Construction Stored Carbon

A financial metric for carbon storage in the built environment

ASN Bank & Climate Cleanup

Gideon
Open Natural Carbon Removal and Storage Metric Series

This document is part of the Oncra Metric Series, a quartet of metrics covering all major scalable natural carbon storage biomes and ecosystems. These metrics are primarily developed for the financial sector but accounting methodologies hold over other sectors as well. Oncra stands for Open Natural Carbon Removal Accounting, developed by Climate Cleanup Foundation in order to enable climate innovators to account for and monetise the climate value they add by removing carbon while regenerating nature.

Parallel to Construction Stored Carbon we develop Land Stored Carbon, as these carbon storage methods are currently best developed. Ocean Stored Carbon and Rock Stored Carbon generally offer more potential for fast distributed scaling of carbon removal, and offer huge opportunities for innovation. If you are or know about potential ecosystem partners for the further development and implementation of these metrics you are invited to contact us at csc@climatecleanup.org.
Construction Stored Carbon
A financial metric for carbon storage in the built environment

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Land Stored Carbon
A financial metric for carbon storage in the grown environment

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Ocean Stored Carbon
A financial metric for carbon storage in the marine environment

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Rock Stored Carbon
A financial metric for carbon storage in minerals

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Summary

Biobased buildings store carbon.

The climate emergency necessitates reduction as well as removal and storage.

There is a need for separate targets for emission reduction versus removal, as subtracting removal from emissions to work towards ‘net-zero’ targets can easily lead to greenwashing and related negative systemic transition effects. The ‘Oxford Offsetting Principles’ offer guidance.

The use of biobased materials in constructions substitutes carbon intensive materials, offering an extra, substantial multiplier effect. This will help to decarbonise the construction industry as biobased materials have a much lower carbon impact than materials like concrete or steel.

Construction Stored Carbon (CSC) is a metric to account for physical carbon stored in biobased buildings and infrastructure, in project investments or portfolios.

CSC aims to solve questions around storage duration by bringing lifespan in line with the (arbitrary but well accepted) 100 year timeframe that now demarcates short-term from long-term storage.

CSC/100y is thus a measure to indicate the long term carbon storage in buildings.

‘End of Life’ assumptions seem flawed (these are assumptions in life cycle analysis scenarios about what happens after recycling options are exhausted). These assumptions currently boil down to: all biobased materials are burned. Given physical climate impacts and legal developments around climate and CO2 emissions it seems likely that burning materials by end of life will be soon very unlikely and, especially in 50 years time, even forbidden. Using correct assumptions unveils the actual, physical long term storage potential in biobased materials.

CSC helps to expand positive climate impact opportunities from just energy related measures towards the inclusion of carbon storage, and regenerative impact: buildings as real climate solutions.

CSC creates a new revenue model for agriculture that is under severe pressure due to both nitrogen and climate emissions and policies. Exhausted soils caused by mono crops and heavy fertilisation can be restored, including the biodiversity in the soil and surrounding areas.

Contrary to intuition, and especially where Chain of Custody (CoC) certification is available, it may be supposed that the use of biobased products leads to more sustained well managed forests and non-food agriculture. Especially in that case the CSC can safely be considered to be additionally stored carbon in both buildings and soil. If carbon credits would be created using CSC for timber construction, these would in most cases be additional as most voluntary forestry crediting schemes prohibit creating credits for biomass sold as timber or other construction materials.

Systemic effects in value chains (like more forests, facilitating climate transition in construction industry and agriculture, but also human health advantages) provide this approach with leveraged impact.

Existing LCA methods and updated EN norms offer enough conceptual space and open data (e.g. increasingly in EPDs) to do robust assessments.

Assessment of CSC in projects and portfolios is an opportunity for financial institutions, both to indicate positive climate value and to mitigate financial climate risk by identifying investments with positive exposure to climate solutions.
Publishing aesthetics of urgency

Under the current conditions of climate crisis, a metric description like this one cannot be a static document. For this reason, first the graphic design choices are optimised for fast updates (permanent beta) and online publication. Second, this text is intended to exist as a living document. It is published under CC BY-SA licence on csc.climatecleanup.org. A version history is at the end of the document.

Comments and improvements are highly encouraged and can be done directly in the document. Finally, the metric and principles description will live apart from the cases. Developers working on biobased buildings are invited to add their work. The calculation model is open and freely available, so all you need to do is post a picture and description of your project, plus email a copy of the calculation. The authors hope that this way this place will grow into a widely useful and impactful information hub.

Acknowledgements

We would like to express our gratitude to the following people, who contributed advice, inspiration, corrections, ideas and more. Although all feedback is highly valued, the responsibility for the metric design, text and conclusions remain entirely with the authors.

We especially thank Marcel Beukeboom (former Climate Envoy Kingdom of the Netherlands), Jaime Bourbon de Parme (Climate Envoy Kingdom of the Netherlands), Mark Compeer (Nice Developers), Pepijn Duijvestein (New Economy), Hans Eerens (PBL), Peter Fraanje (TNO), Tine-Loes Hemmes & Marc van Os (Dura Vermeer), Adriaan Korthuis (Climate Focus), Gijs Kuneman (Unie van Bosgroepen), Mantijn van Leeuwen (NIBE), Jos Lichtenberg (em. prof.dr.ir. TU Eindhoven), Giel Linthorst (Guidehouse, Platform Carbon Accounting Financials), Dennis van Lith (FLETTS), Alex Meerkerk (EcoCabins), Pim Mossou & Joost Meerman (MEMO), Gert-Jan Nabuurs (Professor European Forest Resources, Wageningen University), Sandra Nap, Chantal van Schaik (Holland Houtland), Norbert Schotte (VORM Architects), Detlef P. van Vuuren (PBL, IPCC), Ruben Zonnevijle (DGBC).

ASN Bank is a bank with the mission to foster environmental and social sustainability. We use the money that our customers entrust to us to promote sustainable development. We thus help to create a world that is safe and healthy for people to live in, and where the environment is respected, both in the present and in the future.

Gideon is changing the construction industry in a positive way, so that it contributes to a sustainable, healthy, pleasant and beautiful living environment, now and in the future. We do this by forming self-directed tribes.

Climate Cleanup is a non-profit foundation and social enterprise funded by members and well-aligned partners. Our mission is to reverse climate change by doubling nature to remove 1500 gigaton CO\textsubscript{2} and foster a new nature economy. We are grateful to our members as without their support this work could not have been done.

The creation of the metric and this report is an intervention team effort, mostly by Andy Dockett, Freek Geurts, Jan Willem van de Groep, Hanny van Hout, Sven Jense, Jeroen Loots, Pablo van der Lugt, Hendrik Snijder, Piet Sprengers, Sanne Stadler, Tijn Tjoelker, Bart van Valenberg, and Emmelien Venselaar. We are grateful for the joyful collaboration and hope to have created the seeds of an idea that will enable and enhance the (re)creation of a beautifully built future for our children, further generations as well as other life.
Preface

For climate diplomats the main arena has long been the international meeting room. Important results were booked, ranging from the mother of all climate agreements – the Earth Charter of Rio de Janeiro in 1992 – to the Paris Climate Accord in 2015. One could say the frame of the global climate regime has been built. Maybe still some plaster and a little paint, but ready to be used.

Enter a new phase. The phase of actual implementation. How are we going to make those lofty goals of mitigating emissions, building resilience and financing the transition a reality? Many climate diplomats, including myself, had to step out of their familiar arena and take up a new role. Although agreed between governments, these objectives apply to all of us! Recent court rulings confirm this: governments, citizens, companies – we are in this boat together.

Climate diplomats therefore engage in the energy transition, convincing stakeholders to switch from fossil to renewable. We include the younger generations, as this reconstruction of our economy and society requires new perspectives and innovative ideas. With the Paris Agreement as our job description we also stepped into the financial sector, pointing at article 2.1c. ‘Here, it says we have to align all financial flows with the climate goals of mitigation and adaptation’.

That is a major shift, as a lot of capital is invested in sectors, products and processes that are polluting and contributing to a changing climate. To make things more difficult, the safest bets for big investors are the ones responsible for the largest share of emissions, like heavy industries and international oil companies.

However, I see a growing willingness to align financial flows with the Paris objectives, partly because pressure from the outside mounts. Fortunately it also changes because financiers and businesses see that climate smart investments are the most futureproof. The phase we are now entering is the one where we have to know how we are doing, tracking progress and raising ambition along the way. That is where metrics like the one presented in this report come in.

I applaud ASN Bank and Climate Cleanup Foundation for stepping in each others’ arenas to develop this initiative. Both the agility to look at the issue from a new perspective and the metric itself are examples worth copying. I hope many people will.

Marcel Beukeboom
Climate Envoy
Kingdom of the Netherlands
Notre-Dame on fire

Photo: LeLaisserPasserA38, CC BY-SA 4.0, via Wikimedia Commons
### 1. Introduction

In April 2019, a fire broke out in the Notre-Dame de Paris. With the cultural heritage, an amount of ancient carbon went up into the flames. The cathedral had largely been completed in the year 1260. That means the wooden construction had been storing carbon that had been removed from the medieval atmosphere, as carbon dioxide, by trees over 750 years ago. All that time, that carbon had not been heating up our climate, until it was released only so recently. Buildings do have the capacity to store carbon over time and keep it from worsening global warming. Can buildings be part of the climate solution? Can constructions be actually climate positive?

In 2018, a year before the Notre-Dame fire, ASN bank set itself an audacious goal for 2030: to be climate positive not only in its own organisational emissions but also in terms of the climate impact of its investments and loans. To share knowledge and increase impact, the bank earlier had initiated the Platform Carbon Accounting Financials (PCAF), which at time of writing enables 169 financial institutions, including Blackrock and Bank of America, to measure and disclose the greenhouse gas emissions associated with their $54.5 trillion portfolio of loans and investments. The question how to reach the climate positive goal and how to approach carbon removal and offsetting, also within the PCAF framework, has quickly become relevant.

Becoming climate positive means that not only emissions have to be reduced, but also carbon dioxide has to be removed from the atmosphere. These kinds of goals are increasingly expressed as ‘net-zero’ goals, the ‘net’ suggesting that emissions are compensated or offset by removals. Net-zero however carries a risk of greenwash, for example when profitable fossil fuel based industries plant trees to remove their emissions without reducing them actually. This is even more problematic because the emission happens directly but the removal happens over 30 years with several uncertainties.

Because of these concerns, a group at Oxford University has launched Oxford Offsetting Principles. These principles state that first all possible efforts at reducing emissions have to be made before actual removals of carbon may be used to compensate for remaining, non-avoidable emissions. Construction Stored Carbon is a way of removing those non-avoidable emissions, at timescales that are as good as permanent given the current climate emergency. Removals should not be used as a means of winning public support for continued emissions; in other words, greenwashing.

If these Oxford Offsetting Principles are met, storing carbon in constructions can change the way we look at the world and help recreate a stable climate. We may start to imagine a world wherein materials are grown and all our constructions, buildings but also infrastructure like roads and bridges, is storing carbon, keeping greenhouse gases out of our atmosphere for extended periods of time. Given the climate crisis it is a necessity to create incentives for storing carbon, and for keeping it stored away for as long as possible. Financial institutions may play a major systemic role in fulfilling this promise. And governments can ensure that carbon storage is financially valued as they do for so-called CCS (Carbon Capture and Storage) projects where CO₂ is captured and stored underground. The cost price is around €125 per ton. Subsidies offered by for example the Dutch government bridge the gap between this cost price and the market value of CO₂ within the EU Emission Trading System (ETS). From that perspective the value society attaches to CO₂ storage is already €125 per ton. For a crop like hemp, through a combination of displacement and storage, this would translate to a value of €3.375 per hectare.  

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5. Calculation by Jan Willem van de Groep, available upon request (janwillem@vdgroep.nl).
The systemic role has another dimension beyond promoting storing carbon: substitution. Mainstream building materials like concrete and steel have large carbon footprints. Concrete alone accounts for about 8% of global carbon emissions. Climate positive (negative emission) alternatives come from biobased materials like wood, hemp and bamboo. Accounting for the carbon these materials store – part of the handprint – reveals their actual value over concrete and steel, because it enables factoring in the shadow price or future damage costs of the carbon emission these materials both avoid (by replacing high emission materials) and actually remove and store. Accounting for and valuing avoided and stored carbon enables creating financial and fiscal tools to help – if not force – companies in the construction industry transition from fossil to biobased value chains in a level playing field.

In this context, the aim of this report is to outline the design of a metric to be used to calculate sequestered CO$_2$ within the value chains of real estate based financial products. This report and the metric it proposes is developed for decision makers in the financial and construction industries, but may also be used by policy makers to design incentives to help the construction sector to transform into a regenerative industry and biobased ‘new nature’ economy. On the European level, the tendency for greenwash by means of ‘net-zero’ targets is addressed by enforcing separate emission reduction and removal targets. Increasingly these targets are moving from nice-to-haves to need-to-haves, as the Paris Agreement is translated into regional and national policy frameworks. Not only do we owe it to our children to provide them with a future; as policies become legally encoded, a solid grip on both emissions and removals in financial products and portfolios seems to become a necessary part of any risk assessment strategy. Moreover, as EU emission trading is being extended from energy towards the built environment, accounting for removal helps to hedge risks but also aids the assessment of climate opportunities.

The Notre-Dame fire confronts us with another fundamental question. In so-called life cycle assessment theory, the accepted way of dealing with the uncertainty of the future is to work with scenarios. If reuse options are exhausted, there are two major end-of-life scenarios used for biobased buildings: burn (for energy), or bury (in landfills). Given the climate emergency and also quickly emerging legislation, this report questions the viability of the ‘burn’ scenario. Do we really expect that in over 50 years time, given the already apparent climate impacts, it will be even permitted (let alone desirable), to release stored carbon into the atmosphere by means of fire? Likely burning at that stage will be a criminal offence. The burn-scenario needs serious reconsideration.

Two years after the fire, reconstruction has begun. This tells us that if we value something, humanity has the audacity to recreate what seems to be lost. Repairing climate damage by reducing emissions and removing carbon is not just about buildings, builders or farmers, it is about our actual future and that of many other species. Accounting for Construction Stored Carbon will enable us to put a value to fixing carbon – a basic building block of life – out of the short term circulation thus restoring the global balance, and reversing climate change.

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Depending on chosen system boundaries, estimates vary.
9 In the reconstruction, remaining wood can easily be reused, while concrete and steel that has been in fires needs to be discarded. This touches on a general misunderstanding about wood: because it burns more predictably than concrete and steel, and actually quite slow, it is actually more fireproof than high emission fossil alternatives.
2. Metric for accounting Construction Stored Carbon

**Distinguishing between short and long term storage**

Construction Stored Carbon (CSC) is a metric that serves to measure physically stored carbon and bridge the conceptual gap between short and long term storage. Reducing, replacing, removing and storing carbon are different actions influencing global warming in different dimensions in time. In carbon accounting practice, one hundred years is the de facto cut-off point\(^\text{10}\) to make the distinction between short-term and long-term storage. A one hundred year timeframe is considered\(^\text{11}\) long term. While biobased construction materials last anywhere between a few years and over a thousand, most assessment methods and standards have not been allowing accounting for carbon storage by biological materials.\(^\text{12}\) Some decades ago this made sense, because accounting for stored carbon might overstate positive climate impact. At this moment in time however, this conservative approach results in the opposite: an understatement of the advantages of biobased construction. Not accounting for the carbon stored neglects the fact that in reality carbon is kept out of the atmosphere, even if it is for less than 100 years. It seems unclear how long a building lasts, as “issues of building lifespan are inadequately addressed” in the scientific literature (Marsh 2017). However, as half of current EU housing stock was built before 1970, a 50 year absolute minimum lifespan is to be expected, while 120 years seems plausible.\(^\text{13}\) This means that carbon stored in buildings is at least ‘semi-permanent’, and especially given recent policy developments (like circular economy legislation) it is increasingly likely that buildings (and materials) will last well over 100 years. Within this context, CSC is an actual answer to the question how to account for this, by IPCC definitions, permanent carbon storage, so as not to over- or underestimate the positive climate impact of biobased building materials and hasten the transition towards a sustainable construction industry.

The CSC metric is also an answer to the growing demand for separating targets for emissions, avoided emissions, removal and storage.\(^\text{14}\) Separating these metrics, instead of aggregating them into a single carbon impact number over the full life cycle of an investment, will both reduce greenwash and enable actors from the financial, construction and other sectors to set specific goals for storing carbon and thus actively help to steer on reversing global warming instead of just prolonging overdue public licences to operate.

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\(^{10}\) See for a discussion below, ‘100 year timescale’.

\(^{11}\) Ibid.

\(^{12}\) This is denominated as the 0/0 versus -1/+1 method in LCA practice (Hoxha et al. 2020).

\(^{13}\) [https://ec.europa.eu/energy/eu-buildings-factsheets_en](https://ec.europa.eu/energy/eu-buildings-factsheets_en) on May 3, 2021 and [Nunen, H. van 2010](https://www.nunen.com). Commercial property seems to have shorter lifespans, however no reliable data is available.

\(^{14}\) This is further explained in the next chapter, ‘Disentangling reduction and removal’.
Circular economy vs. extractive economy.

Extractive economy

Raw materials \(\rightarrow\) Manufacturing \(\rightarrow\) Packaging \(\rightarrow\) Distribution \(\rightarrow\) Use \(\rightarrow\) Disposal \(\rightarrow\) Incineration

Circular economy

Raw materials \(\rightarrow\) Manufacturing \(\rightarrow\) Packaging \(\rightarrow\) Distribution \(\rightarrow\) Use \(\rightarrow\) Disposal

Circular economy vs. extractive economy.
Description of the metric

Construction Stored Carbon (CSC) is a project and portfolio analysis metric measuring the amount of carbon dioxide (CO₂) stored in constructions (e.g. buildings) for at least 100 years. The metric indicates the weight of biogenic carbon (stock) contained in the construction materials, assessed as products and converted to the equivalent amount of CO₂ that was sequestered in the process (flow) of growing the material. Construction Stored Carbon indicates how much CO₂ is being kept out of the atmosphere by biobased constructions functioning as carbon sinks, and therefore does not add to global warming during time of storage.

\[ CSC = CC \times \frac{L(max100)}{100} \]

To derive CSC from a list of materials (by weight or volume), this translates to:

\[ CSC = V \times \rho \times \frac{C}{W} \times \frac{L(max100)}{100} \]

<table>
<thead>
<tr>
<th>symbol</th>
<th>description</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSC</td>
<td>Construction Stored Carbon</td>
<td>kgCO₂/100y</td>
</tr>
<tr>
<td>CC</td>
<td>Carbon in Construction</td>
<td>CO₂ in kg</td>
</tr>
<tr>
<td>V</td>
<td>Volume of material (product)</td>
<td>m³</td>
</tr>
<tr>
<td>( \rho )</td>
<td>Density of material</td>
<td>kg/m³</td>
</tr>
<tr>
<td>C/W</td>
<td>CO₂ content per weight</td>
<td>kg CO₂/ kg material</td>
</tr>
<tr>
<td>L(max100)</td>
<td>Lifespan (product or construction) with a maximum of 100</td>
<td>year</td>
</tr>
<tr>
<td>( \Sigma )€</td>
<td>Total project investment / portfolio value</td>
<td>€ (or other currency)</td>
</tr>
</tbody>
</table>

Volume and density have to be considered at appropriate moisture levels (see also Norms and standards - A1 module).

To enable the comparison of carbon storage capacity between projects, CSC may be divided by the floor space of the project or building.

\[ \frac{CSC}{m^2} = CC \times \frac{L(max100)}{100} \times \frac{1}{m^2} \]

Finally, the metric of CSC, which is now by definition CSC for medium to long term (100 years or more), may be assessed on a per Euro (or other currency) basis to compare projects, loans, investments or portfolio’s on their carbon storage efficiency. This metric, CSC/€, will reflect an investment’s ‘stored carbon
intensity’ (SCI) just like emissions per investment are referred to as ‘carbon intensity’ of the investment. This results in the following equation.

\[
\text{Stored Carbon Intensity (SCI)} = \frac{CSC}{\varepsilon} = CC \times \frac{L(\text{max}100)}{100} \times \frac{1}{\Sigma \varepsilon}
\]

Note that the 100 year timeframe does not mean the metric can be translated into a yearly storage value. Division by the lifetime in years would lead to a lower value for projects with a longer lifetime, and also removal (flow) and storage (stock) exist on other logical levels. The sole reason for a compensation factor for product or building lifespan is to enable honest comparison between long term storage projects, by converting the stored carbon weight to a ‘100 year equivalent’, only if the lifespan is less than 100 years.

**Usage**

The metric of CSC is intended for use in project or portfolio analysis in the financial sector, as well as by decision makers in the construction industry and policy fields. A second group of users may be found with parties looking to offset carbon emissions with carbon storage certificates. In the so-called voluntary carbon offset context the metric may find immediate use, as there are no legal restrictions or obligations on the projects or certificates used for offsetting. The compliance markets currently have no (or very rudimentary) provisions for removal certificates. In the chapter on Principles and Requirements it will be argued that those provisions will likely be made, as for example in the European policy context there is a lively debate about the need for separate reduction and removal targets. When separate removal targets are set, a metric for removal in constructions might be adopted into legal frameworks where the metric will help avoid double counting of carbon sequestered and removed.

15 This CSI does not necessarily reflect the ‘degree of sustainability’; an expensive building with the same amount of CSC will have a lower CSI compared to a more cheaper building, but the costs of course do not have to relate to the amount of carbon stored. To make effective comparisons, more aspects should be considered, and more intricate approaches can be found, like comparing only the costs of the materials and handling costs of the construction layers, excluding non-constructive finishing elements.
Sequestration by photosynthesis and other carbon sources

Carbon removal in biobased construction is based on the natural process of photosynthesis. Photosynthesis is the basis of a process that enables the storage of carbon, by converting and sequestering carbon dioxide (see below, ‘Carbon dioxide and carbon’), mitigating climate change. While a very basic concept, this means that in a biobased economy our construction products will be grown instead of mined; eg. plants and trees grow, while lime for cement is taken from fossil, ancient (mostly) biogenic (e.g. seashell) deposits. This perspective highlights the actual similarities in the comparison between fossil versus renewable energy on the one side and conventional versus biobased construction on the other. Stabilization of the climate necessitates a transition from an economy based on old plants and animals (fossil fuels, cement) towards one based on new plants; from the use of old solar energy towards direct solar energy use through either solar panels, wind and water energy, and new plants. In this sense, measuring for construction stored carbon enables incentivising the shift from fossil to renewable construction practices.

Carbon dioxide and carbon

When the gas, carbon dioxide, is taken up through photosynthesis, the carbon and oxygen molecules are separated, the oxygen is released and the carbon gets stored. Measuring this carbon in CO$_2$ equivalent units has become the standard in carbon accounting practice. Converting from weight in carbon to weight in CO$_2$ is done by multiplying the number by 44/12\textsuperscript{16} (1 kg carbon is 44/12kg CO$_2$).

Other greenhouse gases not measured

CO$_2$ is not the only greenhouse gas. CSC however does not measure other greenhouse gases. Other greenhouse gases, like methane (CH$_4$) and nitrous oxide (N$_2$O), are currently out of scope of the metric, for the sake of simplicity and swift implementation. However, these gases are relevant in reality. Accounting for these gases will only show a more positive climate impact, so for now the choice to omit them is very likely a conservative one, leading to not overstating positive impacts. When a systemic value chain perspective is taken, it becomes apparent that agricultural practices used for growing ‘construction crops’ (wood, hemp, et cetera) replace practices with high methane and nitrous oxide emissions, like dairy farming. So while currently these are kept out of the scope of this metric, the actual positive climate impact of biobased construction practices is even better than this metric indicates.

Materials and products

To assess the carbon content we need to know which material is used. In carbon accounting for emissions, standing practice is to work with emission factor databases. For (biobased) building, however, architects and construction companies choose or order products, made by specific producers, rather than materials. Products like a CLT panel, bamboo element or hemp-lime building block come in certain sizes, made from specific fibers, wood and glue, with certain physical properties. For the metric to be applicable in practice, it is therefore advised to assess products instead of materials. The carbon content of these products (converted to CO$_2$ equivalent) is increasingly available in LCA data, de facto standardised in e.g. Environmental Product Declarations (EPDs)\textsuperscript{17} all described in well established norms (see chapter Norms and Standards).

\textsuperscript{16} The atomic weight of carbon (C) is 12 atomic mass units, oxygen (O) is 16, there are two oxygen atoms in CO$_2$ so the total weight of carbon dioxide is 12 + 2x16 = 44.

\textsuperscript{17} The EPD is a widely accepted description of a product’s environmental impacts, defined by the International Organisation on Standardisation (ISO) as a standardised life cycle analysis aiming to facilitate comparison between similar products. In Europe the EPDs for construction products are guided by the European norm EN15804. In The Netherlands, material databases are available from amongst others the Nationale Milieu Database (NMB) and NIBE.
The construction cycle. Adapted from wri.org/buildingefficiency

Substitution of emissions from conventional materials

Most biobased materials in constructions substitute products that do not store carbon but, to the contrary, come with substantial emissions. Put simply, construction timber can replace concrete and steel. While the complete life cycle comparison between a biobased construction and its conventional version can be complex, recent analyses have shown a useful consistency in this substitution factor. For order-of-magnitude comparisons, prudent use of this factor can be advised, especially as the substitution effect more than doubles the already positive climate impact of biobased buildings compared to fossil construction practices.

On average, a ton CO₂ in wood represents 1,2 ton CO₂ avoided through the replacement of conventional materials. Three recent literature studies underwrite this factor; they can be found in the table below. Leskinen et al (2018) (Substitution effects of wood-based products in climate change mitigation) is both the most recent, and its conclusions fit in between the studies by Sathre and O’Connor (2009) (Meta-analysis of greenhouse gas displacement factors of wood product substitution) and Rüter et al (2016), (‘ClimWood2030’ report). For this reason, the authors advise the use of 1,2 as a substitution factor and have incorporated this factor in the free and open calculation tool that accompanies this metric.

<table>
<thead>
<tr>
<th>Substitution factors</th>
<th>kg C in wood vs kg C avoided</th>
<th>ton wood (dry) vs ton avoided CO₂</th>
<th>m³ wood (500 kg/m³, dry) vs ton avoided CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sathre and O’Connor (2009)</td>
<td>2.1</td>
<td>3.9</td>
<td>1.95</td>
</tr>
<tr>
<td>Rüter et al (2016)</td>
<td>0.8</td>
<td>1.5</td>
<td>0.75</td>
</tr>
<tr>
<td>Leskinen et al (2018)</td>
<td>1.2</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Source and analysis: dr. ir. Pablo van der Lugt. The kg C - Kg C avoided found by Leskinen seems most usable, and lies mostly in between the findings by other studies while still being on the conservative side.
100 year timescale

The CO₂ equivalent weight is corrected for the 100 year storage timescale if a shorter material lifespan is to be expected, so that the carbon storage can be compared to other carbon storing materials or approaches. The 100 year timespan is generally used in IPCC modelling and reporting, for example in the first special report on carbon dioxide capture and storage (IPCC 2005). The 100 year time period was based on an arbitrary, political choice made as a basis for the Kyoto Protocol, in dealing with the comparison of the relative global warming potentials of different greenhouse gases (Kendall 2012, Vogtländer 2014). In LCA practice, this 100 year timescale has been adopted as the cut-off point between short-term and long-term storage. For these reasons, the CSC metric is based on this timespan of one century.

Horyuji Temple in Japan, aged over 1400 years, is the oldest wooden building in the world

Photo: Reggaeman, Wikipedia

The actual lifespan of biobased products is generally assessed in the products’ EPDs. General life expectancy is uncertain, but seems in general to be between 50 and 1000 years. Extreme examples are the Horyuji Temple in Japan, the world’s oldest wooden building that dates about 1414 years back, or the Notre-Dame de Paris as mentioned in the introduction. These lifespans imply questions about the practice of not accounting for stored biogenic carbon. As an example, the durability of Cross Laminated Timber panels produced with current technologies is expected to be at least 50 years, extended to over 100 years when properly installed and serviced, and estimated by for example NIBE to be in the order of magnitude of 1000 years. The average lifetime of a Dutch house is estimated at 120 years. While lifespan estimates will be improved upon, this report proposes to take the life expectancy as provided in the products’ EPD or comparable analysis, and convert this to a 100 year lifespan equivalent by multiplying the stored carbon number by the factor lifespan/100 if the expected lifespan is less than 100 years.

There are however strong indications that burning will be soon prohibited. These arguments fall into three categories: legal criminalisation of emissions, circular economy, and biobased economy developments. First, the legal. As for example the Urgenda vs the State case in the Netherlands, as well as the Shell vs 

---

19. Analysis of different EPDs like Stora Enso CLT EPD, Nibe ‘Milieuclassificatie’ database, 2021
21. The approach of converting <100 year storage to a 100+ is emerging as a de facto standard, for example practiced by Carbon Plan, [https://carbonplan.org/research/permanence-calculator-explainer](https://carbonplan.org/research/permanence-calculator-explainer)
Milieudefensie case underline, there is a strong tendency for legal systems to decrease the legal space for activities that lead to greenhouse gas emissions. As actual climate impacts generally seem to happen faster than science predicted, it might be expected that in over 50 years time the emissions of greenhouse gases may be strictly limited or prohibited, which will effectively criminalise the burning of any material at that time.

Second, circular economy legislation like that in the European Union is defined as being 100% circular by 2050, meaning that processes will lead to no waste, so all materials will have to be recycled into something else, at least into physical carbon storage.

Third, the emerging biobased economy is built on new plants, instead of fossil based resources. No longer will oil and gas sourced hydrocarbons be used as chemical inputs, but ‘new’ plant based chemical components. This means that current ‘end of life’ waste streams from construction materials will be chemical resources. All these developments incentivise recycling and re-use, and thereby increase the carbon storage timescale. This means the storage time is generally understated, and the carbon stored in biobased products will in reality be permanently stored.

**Carbon Ledger Approach**

A more precise, but far more demanding approach is to use a registry of stored carbon and develop a process to assess the actual end-of-life of materials and projects. Given the lifetime of typical constructed projects, which often is more than 50 years, the high uncertainties currently will limit the effectiveness of this approach as the lifetime will in almost all cases surpass that of the duration of the financial products. In future expansions of the CSC metric this ledger approach may be developed, in a collaboration on national and regional levels, for example with the Dutch Madaster, and coordinated by for example central banks with a coordinating role for national ministries and the European Commission. Such an approach would enable a precise inventory of Construction Stored Carbon over time, national and international policy goals, and specific inclusion in national carbon inventories and national determined contributions (NDCs).

A final advantage of a carbon ledger approach for Construction Stored Carbon is that it will help to create an incentive not to construct new buildings but to preserve existing ones. While this might negate short term profits for industry parties providing new materials, it will strengthen the renovation sectors.

**Case studies - example calculations**

“SAWA is an unique wooden residential building of 50 metres high with 109 residential apartments and is developed by Nice Developers and ERA Contour. It contributes to biodiversity, accessibility for various income groups and is a place where people take care of each other and nature. In the design, excessive green, perennials and nest boxes are integrated and nearly the whole construction consists of CLT (including the main supporting structure). Biobased building materials were chosen due to the objectives set by the climate agreement of Paris, EU Green Deal, UN SDGs and Rotterdam city but we also strive SAWA to be an example project for future generations, as an important step towards sustainability objectives and to show proof that construction can be done differently: circular, supporting biodiversity and inclusive for all people.”

---

23 This speed-up is seen in many climate systems, but the main indicator for the ‘speed-up’ might be Climate Sensitivity. See i.e. Science Daily, June 24, 2020.
The biobased materials that have been reported for the SAWA project are predominantly CLT and a smaller amount of other wood material. The amount of CLT counts 4,950 m$^3$ and the other wood material counts 495 m$^3$. According to the ICE database, the average CO$_2$ storage in a kilo of CLT is 1.64 kgCO$_2$ and an average density of 530 kg/m$^3$ is assumed. As there is no specific wood type known for the remaining wood material, an average carbon content of 49.76% is assumed with an average wood density of 641 kg/m$^3$.

Now the CO$_2$ storage per biobased material can be calculated. For CLT, this is simply the volume of CLT times its density followed by its CO$_2$ storage factor:

$$4.950 \times 530 \times 1.64 = 4.303 \text{ tCO}_2$$

To calculate the CO$_2$ storage of wood, the following equation is used:

$$S(CO_2) = \frac{n_{\text{wood}} \rho_{\text{wood}}}{1 + (12/100)} \cdot C \cdot 3.67$$

Where:

- $S(CO_2)$ is the stored CO$_2$ in kg/m$^3$;
- $n_{\text{wood}}$ is the quantity of wood in m$^3$;
- $\rho_{\text{wood}}$ is the density of wood at 12% humidity in kg/m$^3$;
- $1 + (12/100)$ is the correction for the humidity;
- $C$ is the carbon content of wood; and
3.67 is the conversion factor to go from carbon to CO$_2$.

Thus, filling in the equation gives us the following:

\[
\frac{(495 \times 641)}{1,12} \times 0.4976 \times 3.67 = 517 \text{ tCO}_2
\]

The total CO$_2$ stored in the construction (CC) - based on the two biobased materials - is thus 4.820 tCO$_2$ (please note that this example calculates with rounded numbers, in Appendix 1 with case calculations, values are calculated with unrounded numbers). To calculate the CSC that is on a 100 year basis, a lifespan of 80 years is assumed for the entire SAWA project. Although NIBE for example gives CLT an expected lifespan of 1000 years and it is more likely, biobased materials will be reused in the foreseeable future. To be conservative, the CSC is calculated for now using a lifespan of 80 years:

\[
\text{CSC} = CC \times \frac{L(\text{max}100)}{100} = 4.820 \times \frac{80}{100} = 3.856 \text{ tCO}_2 / 100 \text{yr}
\]

More case studies can be found in Appendix 1.

What does this mean for different asset classes?

**Project Finance**

The Project Finance asset class for biobased construction includes loan and equity for the specific purpose of construction projects like housing, industrial buildings, or public infrastructure. This report follows the definition, scoping and attribution of emissions as proposed in the PCAF 2020 report.

As per the definition of Construction Stored Carbon, the operation phase ('Use' or B-module phase in life cycle assessments) of projects is not directly relevant for the CSC stock metric; it should be accounted for separately as emissions flow over time. The end of life and reuse phases are to be assessed, as the storage duration is a factor in the evaluation of the stored carbon capacity.
The calculation of embodied carbon includes all energy used to extract, transport, manufacture, build and demolish buildings. The energy consumed by the building during its lifetime is not included. Whole life carbon would also include operation or use phase emissions.

The practical implementation of the metric for project finance consists of an inventory of the carbon stored materials, by either weight or volume, and CSC/m² for comparison of project impacts. This inventory can be an integral part of the due diligence procedure, and may be included in the investment memo by default. The Construction Stored Carbon can then be assessed as a carbon stock by the formulas given above, and attributed to the investment (debt or equity) in the same way and process as emissions, following the standing PCAF methodology (PCAF 2020, p. 70). This stock assessment will be additional to a flow-based analysis on direct emissions due to production processes.

\[
\text{Attribution factor} \quad p = \frac{\text{Outstanding amount} \ p}{\text{Total equity} + \text{debt} \ p}
\]

(with \( p \) = project)

Total financed emissions are calculated similarly:

\[
\text{Financed CSC} = \sum_{p} \text{Attribution factor} \ p \times \text{CSC} \ p
\]
**Mortgages**

The mortgage asset class is defined by PCAF as on-balance sheet loans for residential property (PCAF 2020, p. 84). Currently PCAF covers the energy related emissions, while acknowledging that embodied construction emissions "are important and should not be neglected" and PCAF could "expand its coverage to include these emissions" (ibid.). This current report aims to pave the way towards this inclusion, starting from the robust and readily available data on stored carbon.

Just as emissions are attributed using a loan-to-value approach, the attribution of stored carbon (and whole life carbon in general) equals the ratio of the outstanding amount to the property value at loan origination (PCAF 2020, p. 85). Financed storage can then be calculated as follows:

\[
\text{Financed storage} = \sum_b \text{Attribution factor}_b \times \text{CSC}_b
\]

(with \( b = \text{building} \))

Measuring financed storage in kgCO\(_2\) / 100y enables institutions like ASN Bank to account for the carbon stored in mortgages and other projects. When specified as storage this may be taken into account when working towards net-zero\(^{25}\) and climate positive goals. Just as with project finance, the carbon storage intensity and efficiency can be compared between mortgages and mortgage portfolios using the CSC/€ and CSC/m\(^2\) metrics.

As argued in the chapter on Principles and requirements under Avoiding double counting, the risk of double counting carbon in the growing phase is moderate and can be mitigated. An effective way of mitigating this double counting risk for specific mortgage products could be to demand that carbon storage credits are either not issued at the growing phase or are passed along in the value chain, following the simple principle that the credit goes where the actual carbon is owned.

**Other asset classes**

Asset classes like commercial real estate, equity, agricultural finance and others follow mainly the same logic. The 2020 PCAF report offers ample guidance and Construction Stored Carbon doesn’t require a generally different approach.

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\(^{25}\) The 'net-zero' concept is increasingly debated, as it potentially enables large polluters to continue polluting while pretending to be carbon neutral. See also [The need for separate targets](#).
3. Principles and requirements

PCAF greenhouse gas accounting principles

The core principles of greenhouse gas accounting for the financial sector have been set out in the PCAF Accounting and Report standard report (PCAF 2020), which builds on the principles as set out by GHG Protocol (figure below). Following GHG Protocol the standard requires scope 3 inventories to be complete, consistent, relevant, accurate and transparent, with additional PCAF requirements for recognition, measurement, attribution, data quality and disclosure. These principles all apply for carbon removal accounting as well. The requirements for ‘measurement’ in the PCAF principles already have a provision for carbon removal, stating that “…removed emissions can also be measured if data is available and methodologies allow” (PCAF 2020, p34). This current report aims to complement these methodologies with a specific metric for carbon removed and stored.

To define when a practice can be considered to lead to actual carbon dioxide removal (CDR), Tanzer and Ramírez have laid out four principles (Tanzer & Ramírez 2019). These principles have been extensively quoted and analysed by the EU funded Zero Emissions Platform (ZEP 2021).

The four core CDR accounting principles

1. Carbon dioxide is physically removed from the atmosphere.
2. The removed carbon dioxide is stored out of the atmosphere in a manner intended to be permanent.
3. Upstream and downstream greenhouse gas emissions, associated with the removal and storage process, are comprehensively estimated and included in the emission balance.
4. The total quantity of atmospheric carbon dioxide removed and permanently stored is greater than the total quantity of carbon dioxide equivalent emitted to the atmosphere.

Following these principles ensures that carbon dioxide is actually taken out of the atmosphere, so global warming is geophysically mitigated. Because these principles are somewhat self-evident and well described in the above mentioned sources, this report advises to follow these principles in all carbon accounting practices, and for them to be added to the PCAF GHG Protocol principles for scope 3 inventories. In effect they add full life cycle assessment systematics for carbon removal to the emission accounting requirements (Box above).

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27 Scope 3 refers to indirect emissions related to products or services earlier or later in the value chains. They are opposed to scope 1 (direct) and scope 2 (indirect energy related) emissions.
### GHG Protocol principles for scope 3 inventories

**Completeness**
Account for and report on all GHG emission sources and activities within the inventory boundary. Disclose and justify any specific exclusions.

**Consistency**
Use consistent methodologies to allow for meaningful performance tracking of emissions over time. Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series.

**Relevance**
Ensure the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making needs of users — both internal and external to the company.

**Accuracy**
Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable confidence as to the integrity of the reported information.

**Transparency**
Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.

### Additional PCAF requirements

**Recognition**
Financial institutions shall account for all financed emissions under Scope 3 category 15 (Investment) emissions, as defined by the GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard. Any exclusions shall be disclosed and justified.

**Measurement**
Financial institutions shall measure and report their financed emissions for each asset class by “following the money” and using the PCAF methodologies. As a minimum, absolute emissions shall be measured, however avoided and removed emissions can also be measured if data is available and methodologies allow.

**Attribution**
The financial institution’s share of emissions shall be proportional to the site of its exposure to the borrower’s or investee’s total (company or project) value.

**Data quality**
Financial institutions shall use the highest quality data available for each asset class and improve the quality of the data over time.

**Disclosure**
Public disclosure of the results of PCAF assessments is crucial for external stakeholders and financial institutions using the methodology to have a clear, comparable view of how the investments of financial institutions contribute to the Paris climate goals.

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Additional PCAF requirements of GHG accounting and reporting are derived from the GHG Protocol’s five principles

Source: PCAF 2020, figure 4-1, page 34
CSC based credits: the Oxford Principles

As CSC describes carbon dioxide taken and stored away from the atmosphere, it may play a role in the creation of carbon credits and eventual offsets (certificates used to compensate emissions by individuals, organisations or jurisdictions). Offsetting carries several serious systemic risks, like problematic ‘additionality’: in 2016 the European Commission found that 85% of offsets failed to reduce emissions (Öko-Institut for DG CLIMA 2016). There is also a risk of greenwash: offsetting cheaply and advertising climate neutrality while continuing emissions.

In 2020, a group of experts from across the University of Oxford comprised a set of principles for effective use of carbon offsets, published as The Oxford Principles for Net Zero Aligned Carbon Offsetting, or Oxford Principles (Allen et al 2020). The group tried to answer the question how carbon offsets can be used to deliver net zero emission commitments without greenwash, while stimulating the right kind of credit supply. They identified four principles for responsible offset practices (box below)

<table>
<thead>
<tr>
<th>The Oxford Principles for Net Zero Aligned Carbon Offsetting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cut emissions, use high quality offsets, and regularly revise offsetting strategy as best practice evolves</td>
</tr>
<tr>
<td>2. Shift to carbon removal offsetting</td>
</tr>
<tr>
<td>3. Shift to long-lived storage</td>
</tr>
<tr>
<td>4. Support the development of net zero aligned offsetting</td>
</tr>
</tbody>
</table>

Construction Stored Carbon as proposed in this current report aligns with most of the Oxford Principles. CSC based credits would make high quality additional offsets (part of principle 1) if the price per ton CO₂ is sufficient to cover the potential extra costs for biobased construction. CSC describes carbon removal by definition (principle 2), and long-lived storage (principle 3) depending on the end of life arrangements (see section Burn, Bury or Reuse?). CSC credits are currently innovative, so they are supportive to the development of net zero aligned offsetting (principle 4). Whether the entity buying the offsets cuts its own emissions (principle 1 part 1) is outside the scope of CSC, but apart from that CSC credits align well with the Oxford Principles. In the diagram in the figure below, taken from Allen et al 2020, CSC offsets would fall in category V (Carbon removal with long-lived storage), as the stored carbon in CSC is by default converted to an at least 100 year timescale.
Disentangling reduction and removal: need for separate targets

Now the climate crisis is increasing in actual impacts, and more effective policies are emerging, the need and demand for actual carbon removal and storage is increasing quickly. Removing and storing CO2 (storage might be in the form of carbon) is now a necessity in order to stay within the carbon budget available within the 1.5° and 2°C warming limits defined in the Paris Agreement (IPCC 2018, chapter 2). However, as with offsets in general, a focus on removal carries the risk of greenwashing. So called ‘net-zero targets’ might lead to high-emission portfolios that are ‘compensated’ with removals that will be simply subtracted from the emission numbers. This might be called the ‘get out of jail free card’ for polluters. ‘Net-zero’ provides both a false sense of sustainability (seemingly emissions are zero because they are seemingly removed directly), but is also not in line with necessary changes in the physical global carbon balance, as clearly indicated by the carbon budgets compatible with temperature rises to stay within 1.5° and maximum 2°C. The Paris Agreement demands immediate reduction of emissions as well as carbon dioxide removal. The UN International Panel on Climate Change (IPCC) specifies that compensation of emissions with carbon dioxide removal has to be used only for "emissions from sources for which no mitigation measures have been identified" (IPCC 2018, chapter 2).

A solution for reducing the systemic risk of greenwash is to disentangle the reduction and removal goals, and work from separate policy goals. This is a growing debate in European policy circles, with large repercussions for member states. This disentangling of emission and removal goals both increases the risk profiles for fossil fuel based asset classes, and the opportunities for assets with a biobased character. Separate targets will ensure both reduction of emissions as well as increased carbon removal; both more clean energy and more forests as well as construction crop agriculture.

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28 The International Energy Agency recently came to the conclusion that new coal oil and gas exploration is incompatible with the Paris Agreement. [https://www.iea.org/reports/world-energy-investment-2021](https://www.iea.org/reports/world-energy-investment-2021)

29 See for example [Euractive (2020)](https://euractive.com/commission-under-fire-for-including-carbon-sinks-into-eu-climate-goals), Commission under fire for including 'carbon sinks' into EU climate goals
For a financial metric on carbon removal to be future proof, it must start from this principle of separate targets. That means part of the carbon accounting history and practice has to be disentangled, as reduction, avoidance of emissions and sequestration have so far mostly been combined to arrive at net carbon reduction numbers. This is why this report strongly argues against the use of a single full life cycle carbon metric, and for CSC to be a separate metric in carbon removal accounting practices.

The emerging concept of the ‘handprint’\(^{30}\) is useful in making the distinction between emissions and removals. Instead of subtracting stored carbon from the emissions, the handprint as a concept for positive impact, including carbon storage, helps a clear understanding and avoids false claims (greenwash). This aids the separation of targets: the footprint (all emissions) related to a construction should be seen as separate from the handprint, which is defined by for example the Finnish Ministry for Environment as “the net benefits of climate impact that would not arise if there were no construction project”, including biogenic carbon storage.\(^{31}\)

There is also a more fundamental need for separate targets that is rooted in logic. Removal of carbon is measured as flow in time (like ton/year), while storage happens as stocks over periods of time (like ton during x years). Carbon removal is measured in weight per year, while storage is measured in weight stored for a number of years. The metrics for removal and storage thus exist in distinct dimensions; one can not simply add or subtract the resulting numbers. Statements about net storage should always be accompanied by a timespan, like: this building stores 40 tons of carbon dioxide over a 60 year lifespan.

In a systemic analysis covering the process from growth to construction and storage, the two dimensions are of course related. To find out how, the following section starts with a description of sustainably growing biobased construction materials.

### Construction Crops: Growing construction material while increasing biodiversity

Wood (timber products) is perhaps the best known biobased material, but certainly not the only construction crop. In addition to solid biomass (wood), carbon is stored through ‘carbon construction crops’ like bamboo, hemp (hempcrete) and biobased insulation solutions like straw, cattail and bladderwrack seaweed, but also in green roofs, green concrete (with added elephant grass), absorption in green concrete (replacement of sand by olivine), biobased plastics (and more generally biobased polymers), and so on. An important reason for including a wide range of biobased products is that many non-timber construction crops grow much quicker than trees and remove up to four times as much carbon per hectare than forests. Much potential is in replacing wood by hemp and bamboo, which enables taking the positive carbon effects into account for national CO\(_2\) targets. The use of these materials can be sped up easily and quickly by providing incentives. The use of this CSC metric enables those incentives by disclosing the advantages.

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Standing certification practice with timber production indicates that it is possible to, counterintuitively, strengthen ecosystems (e.g. increase forest cover and biodiversity) with increased demand for biobased products. With effective certification in place, increasing demand leads to increasing surface area under well managed production. For timber products it seems to hold that if a Chain of Custody (CoC) certification within either FSC or PEFC schemes is available for a product, it may be supposed that the product leads to at least sustained well managed forests and the CSC can safely be accounted for as additionally removed and stored carbon. The availability of CoC certification is advised as a prerequisite for accounting CSC. A more in depth discussion can be found in Appendix 2.

As currently large surface areas, globally, are degraded and/or in use for large scale mono-crop agriculture, well managed bio material production can lead to increasing biodiversity and stronger ecosystems if the right precautions are taken and the right (perennial) crops are chosen: construction crops that are able to restore the soil structure, add carbon (humus formation) and in general increase life. To secure a net positive climate effect from the use of biobased materials in construction, it is necessary to ensure proper certification as production volumes increase. It is advised that experiences from the forestry sector are ported towards production chains for other products, with Chain of Custody (CoC) certification preferred whenever available.

Avoiding double counting carbon credits

Carbon credits are created for voluntary and compliance (government controlled) markets. For the purpose of CSC, stored carbon is a different class of carbon metric than that used for voluntary forestry offsets. A forestry offset can never guarantee the long term storage involved in CSC, and methods for verification of these credits do not allow carbon in harvested trees to be accounted for. Gold Standard excludes harvested trees to be accounted for, while the Verra method enables decreasing the forest carbon pool by
actively accounting wood removed for ‘wood products’ (Gold Standard 2017, Verra 2009). CSC credits thus, when created for the voluntary markets, assess a separate carbon stock not previously accounted for. This report for these reasons argues that CSC credits likely will, from a systemic perspective, enhance and amplify the positive climate effects of voluntary forestry credits.

In compliance markets, standards for the accounting of forest carbon have not been solidly established. In the Dutch situation, the government delivered a National Forest Strategy. This strategy advises the development of sustainable timber value chains including long term carbon storage and the use of wood to replace high-emission resources, but doesn’t specify carbon accounting frameworks to avoid double counting (Nationale Bosstenstategie 2020). The situation for other jurisdictions will have to be assessed, and precaution has to be taken before CSC is used as a basis for policy making in compliance markets.

Forestry credits - deeper into the woods

Forestry carbon credits have received a lot of critical scrutiny lately (like in a 2020 analysis by Bloomberg). As WWF recently argued (WWF 2021), the actual effect of carbon credits for forestry has a mixed record. Ways forward seem to be more integrated approaches with blended finance constructions replacing forestry credits. Lessons from forestry credits need to be ported towards certification and carbon valuation for other construction crops.

Forestry credits may account for the change in carbon stock over time. The most prominent case is when a new forest is created where there was none before. In that case a new stock of carbon will be established. However, for as long as the forest management plan is not changed, this stock will exist on its own account, additional to the stock created as Construction Stored Carbon. This can be understood when considering a forest as a living system of plants, animals, trees and soil, over time. As a forest develops, carbon stocks in trees, plants and soil increase. At a certain moment however, the carbon uptake levels off. Studies show that moderate logging, the planned removal of trees from full grown (“climaxed”) forest systems, does not have to decrease the overall carbon stock. While soil carbon in these production forests may be lower, this seems to be compensated by increased plant and tree growth (Jevon et al 2019). Forestry credits must take into account the periodic removal of trees, specified in the forest management plan. These credits may reflect carbon in soils and carbon in additional trees, but not in trees to be removed. For this reason the risk of double counting stored carbon in harvested trees is moderate and can be mitigated.

If carbon storage certificates for offsetting purposes would be based on the CSC metric, a provision is advised to make sure that either no credits have been issued for harvested trees in the forestation process, or that a discount will be placed on the price of the removal credit to correct for what otherwise would be double counting the carbon. This provision could have the form of demanding the producer of the construction material for a declaration that no certificates have been sold for the trees planned for production. Another approach would be to pass the certificate on in the value chain, which would mean that the producer of the product (e.g. a CLT panel) and eventually the project developer would have to buy the forestry carbon storage certificate along with the product, so that certificate can be cancelled if a storage certificate would be sold.

For credits in compliance markets a similar route may be followed. As usually forestry is accounted for in national carbon balances, the CSC adds an extra temporal dimension to this national balance and must be accounted for separately (see above; the need for separate targets).

Systemic value chain effects

Especially now double counting in voluntary carbon markets does not seem to be likely, value chain effects from a systemic perspective become highly relevant. What can be expected to happen across value chains when financial institutions incentivise the use of biobased construction materials? To answer this question we analyse the value chains over time, and assess actual existing systems.
Following the figure above, the intervention in the system may happen between the financing phase and the construction phase whereby a financial institution incentivizes biobased building, for example by offering mortgages at a reduced rate, under conditions for sustainable forestry as argued. This will increase the demand for sustainably sourced construction products like CLT panels, raising their price. This in turn will increase the demand for sustainably grown timber, raising prices, which will promote the use of land for sustainable forestry as forestry business models are strengthened. The increase in sustainable forestry will translate into more available biobased products, so prices across the chain will again level out. Learning effects are likely to even lower prices, but at this level of integrated system analysis uncertainties multiply, for example as legislation, land prices and international trade parameters start to interact.

It is advisable to develop whole value chain approaches so all stakeholders in the value chain are incentivised (from farmer to finance to builders and owners and everything in between). The broad conclusion however seems quite solid: incentivizing sustainable biobased construction may well lead to more sustainable forestry and agriculture. In complex value chain analysis, only real world cases can provide some certainty, like that of Canadian timber. Canada, while being one of the world’s largest producers of forest products, has been able to, using effective certification, retain over 90% of its forest cover over the past half century, whereas on the rest of the planet forest cover has declined by over 50% (Roche et al 2003).

The World Business Council for Sustainable Development has developed a ‘Building system carbon framework’ that aids in the systemic analysis over value chains. The framework includes specific references to the role of financial institutions and investors. The framework, published in July 2020, can be found at https://www.wbcsd.org/Programs/Cities-and-Mobility/Sustainable-Cities/Transforming-the-Built-Environment/Decarbonization/Resources/The-Building-System-Carbon-Framework. A visual representation of the framework is in the figure below.
Norms and standards

Life cycle assessment

Life cycle assessment (LCA) is a way of describing the environmental impact of a product or service, in a process well defined through the global ISO14040 and related standards. The methodology follows four stages, divided into modules (A-D). The modules describe all stages in production, use, disposal and reuse (figure below).
While a lot of work has been done recently in the LCA domain and norms on different jurisdictional levels, “carbon emission calculations often vary in terms of boundaries, scope, units of greenhouse gas emissions, and methodologies” (Fenner et al 2018).

Construction products’ LCAs are the basis for Environmental Product Declarations (EPDs). In Europe these EPDs are standardised via the norm EN15804. Until recently, however, not all stages in the life cycle had to be covered, and stored biogenic carbon had not to be assessed. On 21 June 2019 a major revision was adopted that prescribes reporting on all stages (modules) as well as the inclusion of biogenic carbon in materials. This results in broad availability of reliable data on stored carbon at a product level, starting January 2022 when use of the new norm will become mandatory.

In addition, the European Commission provides a framework for LCA analysis called the Product Environmental Footprint (PEF), developed from a 2008 legislative initiative. The PEF is based on more indicators, including all life cycle stages from the onset and is also focused on enabling business to consumer communication (Ecofys 2014). Work has been done to align the PEF framework with EPD’s and the EN15804 and the recent update of the EN norm can be seen as a result. The EN15804 now also prescribes full (cradle to grave) assessments instead of just cradle to gate. Both PEF and EPDs can be considered as rulebooks for the calculation and description of life cycle assessments. Both PEF analyses and EPDs can be used as data sources for Construction Stored Carbon.

There are some constraints. Most states adopt the global (ISO) and European (EN) norms in the form of national standards, that are implemented with a delay. Additionally, EPDs for innovative or small scale products and producers will not be readily available, as for small producers the costs of an LCA and/or EPD analysis can be prohibitive (Tasaki et al 2017). In these cases, open data from databases like those provided by the ICE project or NIBE can be used, as well as commercially available LCA data. For swift positive climate impact through unified, open and fast implementation of the CSC metric, this report advises to use open data whenever possible. More considerations on open data are found further in this chapter under ‘Open vs Proprietary data sources’.

**A1 Module provides sufficient guidance (EN16449 and EN15804)**

For the measurement of CSC, the updated EN15804 norms are sufficient: the carbon in materials is now assessed (as ‘biogenic carbon’) by default, so reliable data can now be obtained for construction products from assessments for the A1 module, ‘Raw Materials’. This “A1 hypothesis” seems a solid basis for implementing the CSC metric.

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For actual carbon content calculation methodology, existing European norms provide guidance, most notably the EN16449. This norm prescribes how the carbon storage in wood should be assessed, but holds not much more than a basic biophysical equation: the amount of CO$_2$ is based on the amount of carbon per weight at specific moisture content for the specific kind of wood. Although it has not been specified in the norm, the same logic holds for other biobased materials and products.

\[
\text{Product } CO_2 = \frac{44}{12} \times cf \times \frac{\rho \times V}{\omega} \times \frac{\omega}{1 + \frac{\omega}{100}}
\]

In the basis, the weight of the carbon molecules is simply density x volume x carbon fraction, which is then converted into CO$_2$ equivalent by factoring in the atomic weight of the O (oxygen) molecules. In this formula,

- \(Product_{CO2}\) is the weight of CO$_2$ as it would be emitted were the product burned;
- \(44/12\) converts C (carbon) to CO$_2$ (carbon dioxide) weight;
- \(cf\) is the carbon fraction of the wood (mostly around 50%),
- while the last expression describes how weight at a certain moisture content \(\omega\) (in %) is derived from density \(\rho\) (in kg/m$^3$) times volume (V in m$^3$).

As the equation is straightforward, the EN16449 norm enables a plethora of unified data on carbon content of biobased materials, in CO$_2$ equivalent, to be found in the various open and proprietary databases. For all practical purposes of portfolio or project assessment we can rely on these data sources as long as they are compliant with the various LCA related norms. Because of the need for separate targets (see above), there is no need to make full life cycle calculations just to assess the Construction Stored Carbon. The systemic difference between avoided, footprint (LCA), sequestered and stored carbon described below further clarifies and proves this point.

**Reduced – Avoided – Sequestered – Stored**

Reduced, avoided, sequestered, and stored carbon are concepts used to describe changes in the stocks and flows of the carbon cycle. They are used widely in carbon accounting practices and work on different logical levels. This means that when considering which interventions are most effective for reducing global warming, the processes can not be simply considered to be a chain through which the carbon moves. The measures have to be considered in coherence but on their own merits.
Avoided emissions are out of the scope of the CSC metric, but their effect should certainly not be underestimated. Research shows (Liskinen et al., 2018) that the displacement factor for wood is 1.2 times the value of the amount of CO$_2$ stored, and for biobased insulations this factor is considerably higher. These avoidances can also be derived from a comparison of the biobased construction against non-biobased alternatives. Climate Cleanup Foundation has developed a free open source comparison tool for decision makers, which can be found at [http://biobased.oncra.org](http://biobased.oncra.org). In the tool, the average 120m$^2$ Dutch house has been chosen as a baseline for comparison. Following this logic, avoided emissions can be derived by comparing the biobased construction with a baseline construction in a jurisdiction. CSC facilitates the calculation of avoided emissions when both a baseline construction and more life cycle data are available.
The Oncra biobased building comparison tool, freely available at biobased.oncra.org. This tool has been developed in collaboration with several construction companies and architects, the Dutch Province of South Holland and Holland Houtland (Chantal van Schaik, Sandra Nap).

Embodied – Operational – Footprint – Handprint – Whole Life Carbon

Several overlapping and potentially confusing terms are used for denoting carbon associated with buildings. For example, footprint carbon in most definitions is embodied carbon plus operational emissions (like cooling/heating energy use). Handprint and Whole Life Carbon are emerging concepts useful to disentangle the confusion between footprint, handprint and embodied carbon. To arrive at a full impact concept, the World Green Building Council, Dutch Green Building Council and others are pleading for a whole life carbon approach (WGBC 2019, DGBC).

Life Cycle emissions are the emissions induced in all life cycle phases (‘modules’) of production, use, recycling and disposal. These emissions are also called embodied, however this term is somewhat confusing as it literally means ‘carbon in the body of the product’, which is in fact the carbon stored. Also, use phase emissions are sometimes included into the embodied carbon definition. For this reason this report uses ‘whole life carbon’ to indicate embodied carbon. These emissions have been concisely defined as “the resultant emissions from all the activities involved in the creation and demolition of a building. It is the total life cycle carbon minus the operational carbon impact.” (RICS 2012).

34 Footprint carbon describes all emissions associated with a building over its lifetime; materials, construction, use and end-of-life. Embodied carbon typically excludes the use phase emissions (RICS 2012). Handprint is defined by the Finnish government as the “net benefits of climate impact that would not arise if there were no construction project”, with stored carbon being an important part of the handprint (Ministry of the Environment Finland 2019).
Simplified dynamic assessment of biogenic carbon

The CSC metric works in the realm of storage, but is intimately connected to the whole carbon cycle and thus product life cycle. This connection has to be considered from a systemic perspective. Interactions between storage and sequestration are always complex; if storage increases (for example because financial incentives are provided), this will have systemic effects further down the production chain (like expansion of production forests) that are hard to predict. Feedback loops will have to be taken into account. This complex relationship, and how to deal with it in a financial context, is somewhat evaluated earlier under ‘Systemic value chain effects’. For practical purposes, this report proposes the simplification that stored CO₂ reduces the footprint of a building with the amount stored for as long as the building materials last. It is however necessary not to use just this ‘net-footprint’ number (see ‘Disentangling reduction and removal’) and keep the CSC as a separate value.

CSC does only aim to measure the actual amount of CO₂ taken out of the atmosphere for at least 100 years; it is not meant to be considered as or expanded into full LCA analyses. For this reason, a dynamic assessment of biogenic carbon as proposed by for example Hoxha et al (Hoxha et al 2020) is not necessary. The systemic effects over value chains, as argued, are highly complex and chaotic. Unsurprisingly “there is no clear consensus on how to model the biogenic carbon released or absorbed during their life-cycle” (Ibid.).

This report argues that current attempts to integrate biogenic removals into single net life cycle assessed global warming (GW) values are based on a logical mistake, as the time dimension for storage (a stock) is fundamentally different from that for flows, and end-of-life assumptions are fundamentally uncertain under the current climate emergency. When in the coming decades knowledge about product lifespan and realistic end-of-life scenarios emerge, it might be useful to use CSC as a basis for more complex ‘pulse response’ formulas taking into account the decay of emitted greenhouse gasses over time. CSC is aimed to simplify a robust assessment of actual carbon stored in construction projects and portfolios. It is designed to be future proof by building on accepted norms and standards, and by disentangling the increasingly complex dynamic LCA calculations and simply focus on the actual carbon, stored for an actual period of time during which it is not doing any climate damage.

Burn, Bury or Reuse? End of Life assumptions under climate emergency

Why are biobased materials currently incinerated, on paper, in most life cycle assessments? From an investment perspective, a risk aware precautionary approach would advise otherwise. From a climate perspective, it seems imminent to replace the assumption of burning in the ‘disposal’ phase (C4 module) with preferably reuse, and otherwise even terrestrial storage, or assimilation into the earth. Current assumptions contradict policies on circular economy in 2050 and the development of a new biochemical industry in which polymers from biogenic carbon play a key role.

Climate change has risen to the top of the global policy agendas, with the Paris Agreement as a prominent marker of the start of a new epoch. Carbon emissions have become, as a result, more expensive as the rising ETS price, amongst others, indicates. But also legal risks are increasing. In 2019 the Dutch government was forced by the Dutch Supreme Court to decrease emissions by 25% against 1990 levels, in what is known as the Urgenda case, and recently Shell lost against Friends of the Earth who demanded a 45% emission reduction before 2030. As the Paris Agreement translates into national law in various jurisdictions, further legal constraints on CO₂ emissions are to be expected.

In this context it may be argued that burning materials from current construction projects after 50 to 70 years might as well be a punishable criminal act, especially under the laws effective in the years 2070, or 2090. Climate impacts will be even much harsher than today. Even today it might be questioned whether the burning of materials is in fact compliant with the Paris Agreement and national climate laws. To presuppose that burning may be permitted in 2070 is in this context a highly unlikely end-of-life scenario,
and the current widespread practice of ‘incineration’ as end-of-life disposal method is not compatible with climate policies as it directly adds to CO₂ levels, which already are dangerously high.

In addition, the fast emerging biochemistry industry will increase demand for the availability of bio-based raw materials, also as residual flows from other sectors, which is also an extrapolation of current policy. Incineration is also not at all the direction governments wants to go with their objectives of being fully circular by 2050. The literal text from the document Nederland Circulair in 2050 reads:

"In concrete terms, this means that in 2050 raw materials will be efficiently used and reused, without harmful emissions to the environment. Insofar as new raw materials are needed, they will be sustainably extracted and further damage to the social and physical environment and to health will be avoided. Products and materials are designed in such a way that they can be reused with the least possible loss of value and without harmful emissions to the environment." This text leaves no room for misunderstanding what the policy will focus on in the coming years. Incineration is by definition not an end-of-life scenario after 2050.

As explained under the section ‘Life cycle assessment’, the European Norm 15804 has recently (21 June 2019) been revised to prescribe the inclusion of ‘biogenic carbon’, which means reporting on the weight of CO₂ sequestered as carbon by means of photosynthesis. The norm has also been extended to enforce the inclusion of end of life scenarios. Based on the legal arguments above, financial institutions (and all other stakeholders) should use end of life assumptions based on reuse or burial scenarios. The assumption of burning materials at the end of the life cycle is from a climate point of view a bet against humanity.

Also there is a systemic problem with the LCA methodology. A positive score on the D Module as defined in the EN15804 standard may currently be used to eliminate negative emissions that are the result of the building process. This is an undesirable (and from a climate perspective dangerous) situation that calls for a correction as soon as possible.

Alternatives for burning are low tech and readily available. Biobased building components like CLT panels can be designed and mounted with the aim of enabling reuse (eg. using standardised sizes, dry-mounting (screws) and so on). If reuse is at some point no longer feasible, burial seems the better option. All over the world there is a massive experience with the practice of waste burial. Where reuse or recycling are no longer effective from an economic perspective, burial is an easy and economic solution to assimilate the carbon back into the earth. Zeng argues how landfilling wood extends the carbon storage from forestry produce from 10 years to a period of 100-1000 years (Zeng 2008, figure below). Based on his calculations, a 5 hectare landfill would suffice to store one megaton of CO₂ in end of life wood products underground, at a cost of $14/tCO₂ (ibid.) Already now these costs are well below actual carbon prices like those of the European ETS (about €56 at time of writing), let alone the shadow / damage costs (about €353/tCO₂, Ricke et al (2018)). As these costs will rise with increasing physical climate impacts and stricter climate legislation especially on the 50 to 100 year timeframe, burial is by far the most economic option. This might lead to the conclusion that already now, the chances of carbon stored in construction materials to last over 100 years may be much higher than anticipated. From a risk perspective, it may be advisable not to be conservative in the assessment of the lifetime (L) factor and thus the \( L^{(\text{max100})}/100 \) factor in the CSC equation. It is advised that a >100 year lifespan is at least considered as the default because of legal developments (stricter emission laws), especially when robust lifespan data is lacking. When no chemically harmful components are present, an alternative for burial can be sinking to a landfill.

36 For example DERIX-Group has set “a standard for taking back used construction components”. https://www.derix.de/en/aktuelles/news/derix-gruppe-bauwende-und-cradle-to-cradle-jetzt
the deep seafloor. The long life of shipwrecks shows that decay is generally slow, and sealife uses debris as a shelter and nesting ground so sinking might improve marine biodiversity.

Open vs proprietary data sources

According to the Open Knowledge Foundation there are three general arguments why one should use open data. When we look at constructing biobased buildings, this can be seen as an innovative way to look at society’s challenge to meet both residency demand and climate goals. Hence, seeing this as an innovation, it can be driven more easily when data is opened. Proprietary data sources would only inhibit the development/transition as each party is “inventing the wheel himself”. This is one of the three main arguments for the use of open data sources. Open data also supports transparency of the innovation allowing other innovators to assess, improve and reuse the data or concepts of the data. This again stimulates further or faster innovation in a sector. Closely related to this, open data makes participation, collaboration and engagement of stakeholders of an innovative development more likely and easy. Open data therefore can realise faster innovation and in the case of biobased buildings enable a faster transition.

There are already several movements and organisations vouching and enabling access to open data more easily. For the case studies in this report the ICE database from Circular Ecology was used to calculate the CSC. For construction materials unavailable in the ICE database, scientific literature was still required and for some more specific construction products the respective Environmental Product Declarations (EPD’s) could be used. The latter is a form of open source data, while the use of scientific literature proves that not all data can be openly accessible and could have hampered the CSC calculations. EPD’s can be found at the specific product manufacturer’s websites or at EPD databases like the EPD library from The International EPD System or the list of published EPD’s from Institut Bauen und Umwelt e.V.

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38 https://www.environdec.com/library
4. Recommendations & next steps

Using the CSC metric, the potential for carbon storage in the built environment becomes apparent. Biobased buildings are shown to be able to be actual climate solutions. In the Dutch context, an estimated one million houses will have to be built before 2030. The potential for storage in these one million houses is in the order of magnitude of 50 megaton CO$_2$, or a quarter of yearly Dutch emissions. Seen in this context, CSC can support mitigating climate disruption by measuring the removal of relevant quantities of carbon dioxide. Financial institutions can play a systemic role in facilitating this transition, while both mitigating climate risk and disclosing climate opportunities.

Given the large possibilities for both risk management and climate opportunity assessment, the authors recommend implementation of the metric for Construction Stored Carbon by a large range of stakeholders in the financial sector. Next steps might include integration of CSC into the PCAF Standard, defining methods for accounting avoided carbon, and extending the CSC towards a climate impact metric by also including ‘doughnut’ factors like nitrogen and well-being. A first step towards this more holistic approach might be to link CSC to biodiversity impact in the PBAF framework. We list further recommendations and next steps below. In digital editions the links refer to related sections in this report, and they may be periodically updated. Readers are invited to share suggestions or improvements via csc@climatecleanup.org.

**List of recommendations**

a. Do account for stored carbon.

b. Implement CSC into the PCAF standard.

c. Relate lifespan of products to **100 year period** and account that fraction (lifespan/100) as permanent storage (specify time horizon of carbon ownership in context of climate crisis).

d. Use the **substitution factor** of 1.2 (1 ton CO$_2$ stored in biobased products substitutes on average 1.2 ton CO$_2$ emissions from non biobased materials), which, in addition to the carbon stored, even doubles the positive climate impacts of biobased construction.

e. **Change end-of-life assumptions** in life cycle analysis from ‘burn’ to ‘reuse or bury’ in order to facilitate permanent carbon storage, on the basis that releasing carbon back in the air will most probably be illegal by the time constructions reach their economic end of life. This will result in a better reflection of the actual value in biobased construction.

f. In Dutch context: enforce that CSC (biogenic carbon storage) is incorporated in the so called MPG (Milieuprestatie Gebouwen).

g. Systemic effects in value chains (more forests, resilient ecosystems, facilitating climate transition in construction industry) are likely positive but only if **conditions of effective certification** are met (Chain of Custody is best).

h. Use CSC to extend the energy focused climate transition towards an also material and nature centered approach (Dutch context: from RES to REKS).

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40. [carbonaccountingfinancials.com/standard](https://carbonaccountingfinancials.com/standard)
41. [doughnuteconomics.org](http://doughnuteconomics.org)
42. [pbafglobal.com](https://www.pbafglobal.com)
43. [regionale-energiestrategie.nl](https://regionale-energiestrategie.nl)
i. Banks might become stored carbon accountants; **Carbon ledger approach**.

j. Develop financial products with the carbon (climate) value as collateral (banking on carbon credits).

k. **Carbon credits** for removal might use CSC as a basis but should conform to the **Oxford Offsetting Principles**.

l. **Open data**: For a unified, open and swift implementation of the CSC metric this report advises to use open data whenever possible.

m. Extend towards a holistic approach, like in Kate Raworth's doughnut model, for example by linking to the **Platform Biodiversity Accounting Financials** (PBAF) approach.

n. Analyse what CSC means for financial institutions' climate (positive) goals: for portfolios, facilitating transitions, including retrofitting buildings, and in order to be a force for positive change.
Appendix 1 – Case studies

Following is a random selection of biobased construction projects, with their total carbon storage, as well as (in case of apartment buildings) the storage per apartment and per average (Dutch) living space of 120m². We thank all developers and architects who made their data available in an open and collaborative spirit.

More cases can be found in the ‘bidbook’ found at constructionstoredcarbon.org at this link.
SAWA is an unique wooden residential building of 50 metres high. It contributes to biodiversity, accessibility for various income groups and is a place where people take care of each other and nature. In the design, excessive green, perennials and nest boxes are integrated and nearly the whole construction consists of CLT (including the main supporting structure). Biobased building materials were chosen due to the objectives set by the climate agreement of Paris, EU Green Deal, UN SDGs and Rotterdam city but we also strive SAWA to be an example project for future generations, as an important step towards sustainability objectives and to show proof that construction can be done differently: circular, biodiversity supporting and inclusive for all people.

"We build on the city with love for the neighbourhood and nature. Pioneering in a sustainable, nature-friendly and social way. We develop SAWA with and for the neighbourhood. SAWA gives something back to the city."
Nature and sustainability were the guiding principles in design, choice of materials and construction method for this elementary school. It is a fully detachable wooden building that completely fits into a circular economy. The wooden construction is part cross laminated timber, part timber frame. Insulation, interior/exterior cladding and furniture are mostly of biobased origin. The building’s components are easily detachable for reuse after it’s lifecycle and an extensive catalogue of materials used has been registered in the building’s material passport. Other sustainable, diverse and innovative materials and techniques: columns out of shaved tree logs, wooden hollow-core floor slabs, (unbaked) loam brick inner walls for thermal mass, acoustic cork panels, natural ventilation shutters, an ice-based temperature buffering system and natural green walls on the indoor and outdoor facades.

“De Verwondering is the first example of a new generation of biophilic school buildings that recognize and utilize the powerful effect of natural principles on the learning abilities of young children.”

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<th>Total stored CO₂</th>
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<td>23,5</td>
<td>tCO₂ / 120m²</td>
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Not only the residents, but also nature is given space, that is the objective of the wood construction demolition-/new construction product “Blokje Opnieuw” by Dura Vermeer. This is done by circular, climate adaptive and nature inclusive construction work. That is why Blokje Opnieuw uses for example sedum roofs, passive sun blinds, planters and climbing plants on the facades. Circularity is complied with by reusing materials to the maximum, creating dismantlable residencies at an element level and minimizing the use of finite resources. By using biobased materials like sustainable wood, we limit the impact on Earth and we realise an optimal living climate.

“Blokje Opnieuw: Circular, Climate Adaptive and Nature Inclusive”
EcoCabins

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<tr>
<th>Total stored CO₂</th>
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<tr>
<td>19.0</td>
<td>tCO₂ / residency</td>
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<tr>
<td>43.9</td>
<td>tCO₂ / 120m²</td>
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In Helmond the neighbourhood of the future is being created, Brainport Smart District. EcoCabins realises here, in collaboration with RED Concepts and Marc Prosman architects, a neighbourhood with 65 innovative, affordable, fully prefabricated wooden houses. Together with future residents, we develop a high quality living environment where people can live in a safe, healthy, smart, sustainable, functional and happy way. Wood construction is for the developers a logical choice because it contributes to all of these objectives.

“In our vision, housing is not about creating houses but about founding a sustainable community”
Studio Marco Vermeulen – The Dutch Mountains

As this project is in development, some assumptions were made. Averaged from three scenario assumptions, scenario 1 was calculated using best guesses of material use and wood type. Scenario 2 was calculated following the assumption that the total sum of wood was of an unknown wood type. Lastly, scenario 3 was calculated assuming the total sum of wood consisted of *Picea* spp. wood. From these three scenarios sample standard deviation was used to estimate the uncertainty.

Eindhoven's railway zone is in full development. With a mix of living, working and meeting, an internationally oriented centre will be built here in the coming years in the Dommel river valley. Two towers with offices, flats and a hotel come together in a collective winter garden. The sculptural building looks different each time from different points of view and ‘moves’ along with the passer-by via the railway or the Professor Dorgelolaan. A large part of the building will be constructed using cross laminated timber (CLT).
In the fully-fledged single-family house blanCO\(_2\), which was developed by MEMO Projectontwikkeling, we apply biobased building materials in a scalable and industrial prefab construction process. Due to the storage of CO\(_2\) in the building materials, an industrialized production process, a short prefab assembly process on the construction site and also detachable and remountable building elements, this house is cleaner and healthier than houses built with traditional building materials.

Prior to the production process, the customer can use the home configurator to adjust the home as desired, so that within a plan, variation arises in facade layout and finish, materialization and home typology. Ultimately, this results in a unique and varied living environment in which large groups of people can live healthily.

"We believe that everyone in the Netherlands should be able to live in a healthy home without burdening the environment! This is possible with blanCO\(_2\)."
Appendix 2 – Forestry certification

An analysis of forestry certification in Europe leads to the conclusion that more wooden buildings result in more forests. This surprising correlation is a result of effective forest certification schemes, and holds only in areas where these certificates are used (like in Europe with FSC and PEFC schemes).

For the purpose of assessing Construction Stored Carbon, a simple criterion is proposed that is expected to hold up well in the European context: if a Chain of Custody certification within either FSC or PEFC schemes is available for a product, it may be supposed that the product leads to at least sustained well managed forests and the CSC can safely be accounted as additionally stored carbon. The systemic dynamics behind this criterion are discussed in Appendix 2.

This report proposes to extend this ‘Chain of Custody argument’ towards other, non-timber biobased materials as well.

Biobased projects require large quantities of biomass. The production of biomass requires large plots of land which poses various land-use risks. Among these risks are biodiversity loss, soil degradation, competition with food production, land appropriation, destruction of primeval forests and other land-use changes. Some of these risks contribute to climate change. All of these risks are potential unwanted side-effects of biobased buildings. Therefore, contractors for biobased construction work should require their biobased material suppliers to only source biomass from sustainable producers. There are a number of certification schemes for biomass that cover above mentioned sustainability risks. These certification schemes can be used by contractors as one of the product properties.

For wood products from forestry, the following sustainable forestry certifications exist:

- Program for the Endorsement of Forest Certification (PEFC): for ethical and sustainable forest management and derived forest products.
- Forest Stewardship Council (FSC): for environmental and socially responsible forest management and guarantees this for the forest products.
- Origine et Légalité des Bois (OLB): allows traceability of the origin for forest and timber trading companies and proves legality of the forest products.
- Sustainable Forestry Initiative (SFI): promotes sustainable forestry management but specifically for the United States and Canada. The requirements include measures to protect water quality, biodiversity and wildlife habitat. Criteria upheld by SFI are less strict than for example FSC.

There are two types of certificates possible. One is the certification of the forest management (FM) and checks whether the forest is being managed according to a set of standards. The other type is the so-called Chain of Custody (CoC) that verifies whether the certified material is identified or kept separate from non-certified or non-controlled material through the production process, from the forest to the end-consumer. To label the end-product as certified, both FM and CoC certifications are required. From the perspective of biobased buildings, a CoC certified product is most relevant.

As FSC and PEFC are most known and recognised certifications, this report will focus on these two standards. Worldwide, more than 223 million hectares are FSC certified (FM) and more than 46 thousand hectares are PEFC certified.

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44 This holds mainly for softwood, as hardwood from tropical forests is harder to track and often leads to biodiversity loss. See for a discussion Voigtlander et al 2014, European hardwood is also available, for example oak.
45 See for additivity within voluntary carbon schemes the next section ‘Avoiding double counting’.
46 Sustainable forestry certification (bureauveritas.com)
47 Forest Certification - Basic Knowledge (fao.org)
CoC’s are FSC certified. More than 324 million hectares are PEFC certified worldwide and in total more than 12 thousand CoC’s are PEFC certified. However, according to the Fair Finance Guide International (FFGI), the two certification schemes are not completely the same. While a FSC certified body needs to comply with all 10 principles and 70 criteria, a PEFC certified body needs to comply with its national standards. These national standards however, are required to at least meet the internationally set standards.

But these national standards are, according to civil society organisations (CSOs), difficult to derive clear criteria from. According to the FFGI, there are numerous other critical points of discussion on PEFC. However, it is worth pointing out that these points addressed are based on reports from before 2018 and that PEFC updated its international standards in 2018. Additionally, a human rights report of 2019 reported that human rights are addressed properly by both FSC and PEFC. Despite outdated references, some organisations base their sustainable wood policy on the FFGI report and deem FSC superior over PEFC. Based on the 2018 updates this seems no longer the case and it can be advised to consider both FSC and PEFC as acceptable certificates.

Looking at the FM of both standards in Europe (Russia completely included), certification distribution is about 50/50 (Figure below). However, significant variations exist from country to country as can be seen in the second figure below. Most FSC certification can be found in eastern Europe. Most PEFC certification can be found in western parts of Europe.

Distribution FM from FSC/PEFC

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48 Facts & Figures | Forest Stewardship Council (fsc.org)
49 PEFC Global Certificates - Dec 2020
50 FFGI Policy Assessment 2018 Methodology (fairfinanceguide.org)
51 Report Profundo (bewustmestout.nl)
52 When there is double certification, the area amounts mostly close to the FSC area. Also worth noticing is that there are multiple countries with almost only one certification standard.
Share of certified forest area, distribution over Europe

Amount of CoC certificates
Looking at the CoC certification under both standards, we see that FSC is responsible for almost 70% of all CoC certificates. Most certificates are obtained in strong economic countries as can be seen in the figure above.

The implications for the CSC assessment are that CoC certification, whether from FSC or PEFC projects, is sufficient to make sure that the stored carbon has not led to deforestation. Even stronger, CoC certification under either FSC or PEFC strongly increases the likelihood of increased forest cover as well as positive and self-reinforcing systemic effects over the value chain.
Carbon Glossary

**Biogenic carbon**
Carbon removed from the atmosphere or water by recent biological growth, as opposed to fossil or mineral carbon.

**CO₂ (ton)**
A ton CO₂ in this report refers to a metric ton, which equals 1000kg. A ton of CO₂ equals 12/44 ton of carbon (see chapter 1, section ‘Carbon Dioxide and Carbon’).

**Embodied Carbon**
In the context of Construction Stored Carbon somewhat confusing term used by LCA analysts to describe all energy and other emissions that went into the production of a product or material. See also ‘Footprint Carbon’.

**Footprint Carbon**
Footprint carbon in materials is the CO₂ that went into making these materials, but the footprint of a building includes use-phase (energy) emissions. Many analysts use the term embodied carbon, however in the context of Construction Stored Carbon this might be confusing, because ‘embodied’ literally means that which is in the actual ‘body’ of the material.

**Whole Life Carbon**
The Whole Life Carbon reflects the total CO₂ equivalent emitted in the context of a building from cradle to grave, including from the use phase. This follows from the Life Cycle Assessment (LCA) of each individual product, and as a concept seems useful to disentangle the conceptual confusion between Footprint and Embodied carbon.

**Sequestered Carbon**
Carbon taken out of the atmosphere by biological or technological processes. Once a reasonable duration of storage is expected (IPCC standards prescribe 100 years or more), sequestered carbon can be considered stored.

**Handprint / Stored Carbon**
Stored carbon reflects the total CO₂ equivalent that remains stored in biobased materials on site after construction. It remains stored (out of the atmosphere) for as long as the building stands and the material exists.
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Roadblocks to biobased building https://library.wur.nl/WebQuery/wurpubs/fulltext/382318


NIBE. Een volledig duurzame en planeet neutrale bouwsector voor onze, én toekomstige generaties. https://www.nibe.org/rl/nieuws/potentiebiobased


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https://redd.unfccc.int


Version history

3/11/21
27/10/21 version has been received by Dutch climate envoy during COP26 negotiatios.

27/10/21
- Addition of over 25 extra cases
- Substitution effect factor added with solid scientific references
- Gideon added as a partner
- Extensive edits based on comments by Jan Willem van den Groep and others

01/09/21
Update based on comments by most notably dr. ir. Pablo van der Lugt
- Handprint concept added
- Section on ‘CSC based offsets’ changed into ‘CSC based credits’, in order not to burden potential credits with the need to serve as offsets (further explanation in that section itself).
- Typo: EN18504 changed into the correct EN15804
- More attention to reuse as ‘end-of-life’ option (from “Burn or Bury” to “Burn, Bury or Reuse”).

14/07/21
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