Understanding the policies and carbon accounting frameworks which are defining the potential role of biobased products to meet climate change targets. LNV-BO-43-128-001

Lesly Garcia-Chavez, Iris Vural-Gursel, Sinead O'Keeffe, Eric J.M.M Arets

PUBLIC

WAGENINGEN
UNIVERSITY & RESEARCH

Understanding the policies and carbon accounting frameworks which are defining the potential role of biobased products to meet climate change targets. LNV-BO-43-128-001

Authors: Lesly Garcia-Chavez[1], Iris Vural-Gursel[1], Sinead O'Keeffe[2], Eric J.M.M Arets[3]

1) Wageningen Food and Biobased Research (WFBR)
2) Wageningen Plant Research (WPR)
3) Wageningen Environmental Research (WENR)

Wageningen Food & Biobased Research
Wageningen, February 2023

This study was carried out by Wageningen Food & Biobased Research, subsidised and commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality.

Public

Report 2388

WAGENINGEN
UNIVERSITY & RESEARCH

WFBR Project number: 6224126300
Version: Final
Approved and reviewed by: Harriette Bos and LNV
Carried out by: Wageningen Food & Biobased Research
Subsidised and commissioned by the Dutch Ministry of Agriculture, Nature and Food Quality
This report is: Public

The research that is documented in this report was conducted in an objective way by researchers who act impartial with respect to the client(s) and sponsor(s). This report can be downloaded for free at https://doi.org/10.18174/588222 or at www.wur.eu/wfbr (under publications).

PO box 17, 6700 AA Wageningen, The Netherlands, T + 31 (0)317 48 00 84, E info.wfbr@wur.nl, www.wur.eu/wfbr.

Contents

Summary

Climate change has become an important challenge at International, European, National and Regional level. Mitigation of climate change by preventing and reducing the emission of greenhouse gases (GHG) into the atmosphere is needed to make the impacts of climate change less severe. To ensure this, different mitigation frameworks have been created. These frameworks set specific GHG reduction goals and provide a more structured approach to solve this problem.

This report aims to provide information to the Dutch Ministry of Agriculture, Nature and Food Quality (LNV) on and how some climate change mitigation frameworks are including the increase forestry and agricultural biomass supply to produce chemicals and materials that can contribute to the reduction of GHG emission.

This desktop research follows a 'systems perspective approach' to study the role of biobased materials' [1] in the reduction of GHG emission. This approach allows the understanding of interactions between biobased products, national inventories and global agreements. Understanding these links and having knowledge on which GHG gases accounting methods are being applied is necessary for the identification of possible drawbacks and for the development of future policy guidelines.

After this review, we conclude that it is important to be familiar with and recognize the value in current existing accounting methodologies. However, existing frameworks are still lacking important features which could enable more robust account methodologies for carbon sequestration and storage in biobased materials. At this moment in time, the European Commission is working on proposals like the 'Carbon Farming framework' and 'carbon removals certification framework' (December 2022) and introducing a 'carbon storage products pool', these proposals could play and important role on establishing clear accounting rules that connect the biomass production to biobased materials and its contribution to support National Policies towards GHG reduction targets. This will require collaboration and information exchange between European countries. Therefore, is important to follow closely the evolution of these frameworks and their proposed accounting rules.

This document is organized in the following way:

- Section 2, introduces terminologies, frameworks and methods for GHG accounting at different levels International, Europe and Netherlands.
- Section 3 is dedicated to understanding how biobased products for could contribute to the Climate targets by substituting other GHG intensive materials, extending the life span of the product or by cascading use of the biomass.
- Section 4 shows two examples on how the GHG balances of two different linear biobased supply chains are estimated at the product accounting level and how this relates to the national level inventory reporting and the global agreements.
- Section 5 presents our conclusions and recommendations.

Keywords: Biomass, Biobased materials, GHG accounting frameworks and methods, Climate Change.

[1] Excluding energy and fuels.

1 Introduction

The transformation of the current fossil based chemical and materials production chains to a sustainable and renewable system seems as an opportunity to contribute to the climate targets on the reduction of anthropogenic greenhouse gas emissions set by the Paris Agreement (November 2016).[2] There is little disagreement that forests and crops sequester and convert atmospheric carbon dioxide (CO_2) to more climate benign forms, such as carbon in wood, agricultural biomass and soil organic matter. This motivates policymakers to consider the role of the forests and agro-system in reducing atmospheric CO_2 and hence mitigate the effects of climate change. Therefore, understanding how the international consensus is evolving to assess the biogenic carbon associated with forest and agriculture-based bioeconomy systems becomes an important discussion point. The materials transition means to replace materials made from (fossil) oil or gas[3] by materials made from renewable carbon (e.g. forestry and agriculture and requires a good understanding of how of biomass[4] production and the increase of carbon stocks in the forest land, crop land and biobased products production contribute to GHG emission accounting.). However, the relationship between absolute GHG reduction (more specifically CO_2) and the increase in the supply and use of biomass in biobased materials is currently unclear. This project attempts to clarify existing information regarding the accounting of GHG emissions of biobased materials from forestry and agricultural biomass excluding energy production and fuels.

The project “Understanding the policies and carbon accounting frameworks which are defining the potential role of biobased products to meet climate change targets” was granted by The Ministry of Agriculture, Nature and Food Quality (LNV) to Wageningen University and Research (WUR) in February 2022. This project contributes to LNV the knowledge and innovation program MMIP B6: Production and use of biomass (Meerjarige Missiegedreven Innovatie Programma).

The main objectives of the project are:

- Provide clarity on how the increase of biobased raw materials (biomass) to produce chemicals and materials could contribute to support National Policies towards CO_2 reduction targets.
- Review the existing methodologies for the accounting of carbon flows to provide recommendation on potential policies measurements that could be implemented.

It is intended that the following contributes to provide more (simplified) knowledge on the potential role of biobased raw materials to The Ministry of Agriculture, Nature and Food Quality (LNV) which is relevant for the formation of discussion panels, on the policy development and on the creation of instruments to support and stimulate sustainable use of biomass. This report intents to provide clarity regarding the following research questions:

- How the afforestation, reforestation and soil Carbon sequestration are relevant towards the reduction of GHG emissions while providing benefits to other sectors with biobased materials?
- How the different GHG accounting frameworks and methods estimates the carbon sequester and stored during the growing of forestry and agricultural biomass (biobased raw materials)[5] and during the use phase of the biobased products?

This report contains a literature review based on known and relevant information recommended by experts from Wageningen Research. The analysis follows a ‘systems perspective approach’ to study the role of biobased products in the reduction of GHG towards climate change mitigation which enables the understanding of interactions between biobased products and national inventories and allows to explore possible drawbacks before implementation. For biobased products (materials and chemicals) there is not yet a harmonised methodology or reference like in the case of renewable energy. There are some new initiatives trying to define

[2] Biobased products: are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised.

[3] Next to metals and inorganic earth minerals such as concrete

[4] Biomass is derived from organic material such as trees, plants, and agricultural and urban waste. In this project we focus only on primary biomass, trees, and plants.

[5] According to the EU Commission “Biomass is derived from organic material such as trees, plants, and agricultural and urban waste”. Source: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomass_en

GHG emissions savings criteria for biobased products. An important recommendation is not to attempt to (re)invent a new accounting methodology but to understand the development and evolution of existing LULUCF and agricultural accounting methodologies, as well as GHG accounting methods at global, EU level and product level.

2 GHG accounting: frameworks, methods and perspectives

Climate change has become an important challenge at International, European, National and Regional level. To have a structured approach to solve this challenge (or problem), different Frameworks related to climate change mitigation have been created. A climate change framework should establish long-term targets that set the strategic direction of a country's efforts to decarbonize and adapt to climate change by progressively reduce GHG gases. The framework gives support to organizations to accomplish sustainable development by setting principles, policies and guidelines to measure and adapt practices towards climate mitigation. (World Bank, 2020)

To measure climate mitigation and to monitor the reduction targets set by the different frameworks, accounting methods are necessary. GHG emissions accounting, refers to the processes required to consistently measure the amount of GHGs generated, avoided, or removed by an entity, allowing to track and report these emissions over time. GHG accounting is useful for states, organizations, and various individuals such as potential investors or stakeholders to delineate how many emissions are they responsible for. GHG accounting methods helps measure three types of climate impact: generated emissions, emission removals, and avoided emissions (PCAF, 2020).

This section introduces some of the most important International, European and national climate change frameworks and GHG accounting methods that attempt to link the carbon stocks in the forest and agricultural lands, biobased products and national inventories.

2.1 Understanding the different GHG terminologies

Greenhouse gases (GHGs) are naturally occurring gases present in the atmosphere which trap heat or radiative energy delivered to the earth from the sun. However, as the concentrations of these GHG gases are building up in the earth's atmosphere, due to anthropogenic activity, so too does their ability to trap heat, which ultimately is leading to changing the climate (IPCC,2021). There are many different types of GHGs in the atmosphere and all behave in different ways (EPA, 2022). Some are more powerful at trapping heat than others (e.g. high radiative forcing potential), some remain in the atmosphere for weeks (e.g. some fluorinated gases) others decades (methane) and others centauries (e.g. CO_2, N_2O). GHGs are not created equally and they can have varying degrees of impact in the atmosphere if released.

Therefore, an important goal for reaching any GHG targets should be to prevent emissions from happening in the first place. This is known as greenhouse gases (GHG) mitigation and it can be defined as all activities and measures which lead to preventing[6] GHG emissions before they can be released to the biosphere or atmosphere in the first place (Minx J. C., 2018) . Examples of mitigation activities include keeping fossil resources unground, or substituting them with lower emitting renewables, activities which led to a reduction in enteric fermentation emissions from ruminant livestock or activities to reduce soil nitrous oxide emissions. Carbon sequestration on the other hand can be defined as the process of capturing and storing atmospheric carbon dioxide (CO_2) in plants, soils, geologic formations and the ocean. Sequestration in other words, removes the CO_2 that has already been released into the atmosphere[7]. It is important to clarify the difference between GHG mitigation and carbon sequestration as this can support a better understanding of how GHG accounting systems can be used more effectively for meeting GHG reduction targets. This is because GHG mitigation and reductions have immediate and permanent impact on atmospheric concentrations and it refers to all GHGs, whereas carbon sequestration only refers to carbon dioxide removal which has already been released, so this approach comes with more uncertainty and is also vulnerable to future releases (McLaren D. P., 2019).

[6] Reductions are intrinsically included in this prevention, as you are preventing a certain proportion of emissions
[7] Methane (CH4) atmospheric pathway also lead to some quantities of CO_2.

Further terms that relate to the field of GHG accounting and carbon targets include:

Carbon pool: A component of the climate system which has the capacity to store, accumulate or release carbon. Oceans, soils, atmosphere, and living and dead biomass (incl. biobased products like timber) are examples of carbon pools[6]. (European commision glossary, 2018), (McLaren D. P., 2019).
Carbon sink: this refers to the ability of a carbon reservoir/ or carbon pool (e.g. forest, ocean, natural environ) to absorb carbon dioxide from the atmosphere resulting in a net sequestration of more carbon than it emits. (Encyclopedia Britannica, 2022).
Carbon neutral: Carbon neutrality, or having a net zero carbon footprint, refers to achieving net zero carbon emissions by balancing a measured amount of carbon released with an equivalent amount sequestered[2] (Moosmann L., et al., 2019)
Negative Emissions: the intentional human efforts to remove CO_2 emissions from the atmosphere after they have been released, ultimately trying to remove more carbon annually from the atmosphere than it is emitted through human related activities. This can be through natural processes (e.g. planting trees) or through technical installations (e.g. Bioenergy with carbon capture and storage) (Minx, 2017) (Minx J. C., 2018).
Carbon capture and storage: Carbon dioxide capture and storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere. (IPCC, 2005) CCS therefore, is usually the term applied when referring to large manmade point sources. This is in contrast to Negative emission approaches, which remove carbon dioxide through fundamentally more diffuse methods (e.g. forests, agricultural soils).
Carbon Capture and Utilization: (CCU) is a broad term that covers processes that aim at capturing CO_2 from flue gas or directly from the air and converting it into a variety of products such as renewable fuels, chemicals, and materials. CO_2 has already been used for decades with mature technologies in various industrial processes to produce e.g. beverages, fertilizers (CO_2 Value Europe, 2022).
Substitution: using a new product to reduce GHG emissions to the atmosphere compared to an equivalent alternative product. i.e. the GHG emissions avoided by using biobased products instead of other fossil-based materials or GHG-intensive materials.

2.2 International Framework on Climate Change

2.2.1 International Panel on Climate Change (IPCC),

The IPCC was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The role of the IPCC is to prepare assessments and technical reports of scientific information on climate change. This includes methodology reports and guidelines, on topics that require in-depth scientific technical assessment, such as the preparation of national GHG inventories. The IPCC precedes UNFCCC and played an important role in its creation and contributed to the formation of the Kyoto Protocol and later to Paris Agreement (IPCC, 2022).

2.2.2 United Nations Framework Convention on Climate Change (UNFCCC) - Reporting of Green House Gases (1994)

The UNFCCC entered into force on 21 March 1994. The general goal is to stabilize GHG concentrations *"at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system."* It also states that, "*such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manne*r".

As of 2022, the UNFCCC has 198 parties (197 States and 1 regional economic integration organization) including all United Nations member states. To enforce the goals of the UNFCCC, the convention has additional protocols. The protocol’s function is to establish concrete actions and efforts for the member countries to limit and reduce emissions of GHG and provide ways to account emission reduction targets. The first protocol was the Kyoto Protocol (1997), which covered two commitment periods (2008-2012 and 2013-2020) expired in 2020 and was replaced by the Paris Agreement (UNFCCC, 2022).

To keep track of GHG emissions by parties to the Convention, all Annex 1 countries (i.e. industrialised countries listed in Annex I to the Convention) need to submit annually a national greenhouse gas inventory report (NIR). The national GHG inventory is a comprehensive listing, by source, of annual GHG emissions resulting directly from human activities and removals of CO_2 in forests and soils. These national GHG inventories use the methodologies of the IPCC Guidelines for National Greenhouse Gas Inventories. Currently for so called Annex I countries (i.e. developed countries) the use of methodologies provided in the 2006 IPCC guidelines (IPCC, 2006) is mandatory, but if duly justified also the 2019 refinements to the 2005 IPCC guidelines (IPCC, 2019) may be used. The GHG emission reporting uses 1990, in most cases, as base year for the emission and covers 5 main inventory sectors (UNFCCC, 2009).

(1) CRF Sector 1. Energy (fuel combustion, industry, incl. public electricity and heat production, transport)
(2) CRF Sector 2. Industrial processes and product use (IPPU, product manufacture and use emissions)
(3) CRF Sector 3. Agriculture (enteric fermentation, manure management, direct and indirect N_2O emissions from agricultural soils)
(4) CRF Sector 4. LULUCF (land use, forestry emissions and removals, living and dead biomass and soils, harvested wood products)
(5) CRF Sector 5. Waste (disposal, composting, incineration and open burning of waste, wastewater treatment)

International aviation and international shipping are memorandum items not included in national GHG totals are not included in national GHG totals.

The EU's GHG inventory report submitted to the UNFCCC is the direct sum of the national inventories compiled by the EU Member States. It is important to highlight that the EU-27, Iceland and the UK, jointly report their national GHG emissions during the second commitment period of the Kyoto Protocol. In the Annual European Union greenhouse gas inventory 1990–2019 and inventory report 2021, the inventory presented the EU GHG inventory under the UNFCCC (scope EU-27+UK) and the Kyoto Protocol (scope EU-27+ISL+UK = EU-Kyoto Protocol)[8]. The main institutions involved in compiling the EU GHG inventory are the Member States, the European Commission Directorate-General Climate Action (DG CLIMA) through its Joint Research Centre (JRC), the European Environment Agency (EEA) and its European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM) and Eurostat. The cooperation and coordination related to compiling the EU inventory is regulated in the Commission Implementing Regulation EU 2020/1208 (European Parliament, 2020). From this it follows that from the 2023 inventory onwards, the EEA takes over the monitoring and reporting of emissions for LULUCF, while Joint Research Centre will focus on research and inventory methodology development.

2.2.2.1 UNFCCC-CRF Sector 4: Land Use, Land-Use Change and Forestry (LULUCF)

The estimation of LULUCF GHG emissions and removals is more complex and uncertain than other GHG sectors because it can be hard to disentangle the simultaneous natural and anthropogenic processes that determine land-related fluxes. Moreover, assessing the atmospheric impact of additional actions in forestry is difficult, because GHG fluxes change over time due to forest age-related dynamics, which is largely determined by previous forest management and natural disturbances (European Commision , 2022).

The "Land Use, Land-Use Change and Forestry" (LULUCF) sector under the convention, encompasses emissions and removals from six land-use categories (IPCC, 2006). However, countries are encouraged to stratify these main groups further through using for example, climate or ecological zones, or special circumstances (e.g. separate forest types in forest land) that affects emissions.

[8] EU-27' refers to the current EU. For reasons of clarity, please note that in some cases the terms 'Member States' and 'EU' and 'Union' may be used. As a general rule, these terms also refer to Iceland and the UK.

- 4A Forest Land: all land with woody vegetation consistent with thresholds used to define forest land in the national greenhouse gas inventory (i.e., relating to minimum values for area size, tree height and canopy cover)[9]. It also includes systems with a vegetation structure that currently falls below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category.
- 4B Cropland: arable and tillable land, rice fields, and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category and is not expected to exceed those thresholds at a later time.
- 4C Grassland: rangelands and pastureland that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as, herbs and brushes, that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas, agricultural and silvopastoral systems, consistent with national definitions.
- 4D Wetlands: areas of peat extraction and land that is covered or saturated by water for all or part of the year and that does not fall into or is otherwise classified by the reporting party under the Forest Land, Cropland, Grassland[10] or Settlements categories.
- 4E Settlements: includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.
- 4F Other Land: It includes bare soil, rock, ice and all unmanaged land area that do not fall in any of the other five categories.

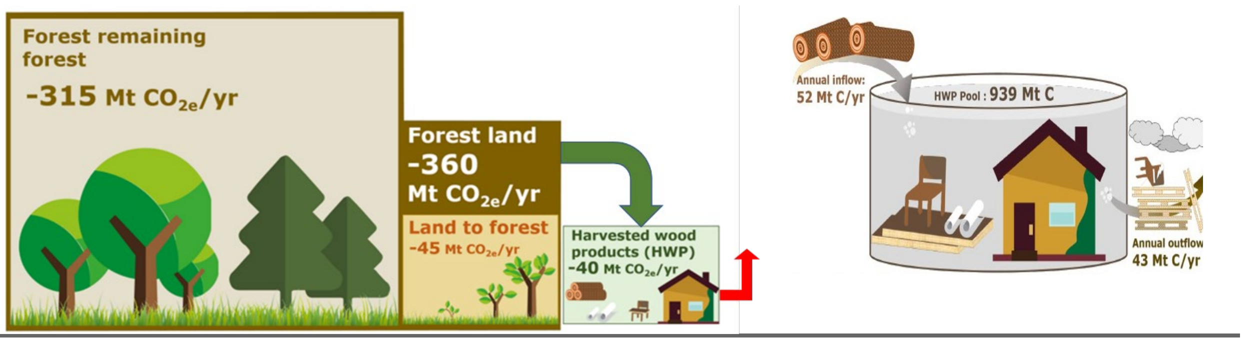
The CRF Sector 4 also includes an additional carbon pool:

- 4G Harvested Wood Products (HWP).

The HWP carbon pool is relevant because it represents and quantifies in a more systematic way how much the forestry-based bioeconomy can contribute to climate mitigation targets set by the Paris Agreement. The HWP pool is only linking forestry biomass to a limited rage of wood biobased product and therefore, to the forest-based bioeconomy. This carbon pool will be explained in more detail in the following section.

2.2.2.2 CRF 4G: Harvested Wood Products Carbon Pool (HWP)

Harvested Wood Products (HWPs) are wood-based materials made from harvested wood taken from forests, which are used for products such as: wooden house materials, furniture, plywood, paper and paper-like products. The HWP is considered a carbon pool because the carbon sequestered and stored in the trees remains in harvested wood until the products made from this wood decay or are burned. (Ruter S., et al., 2019). According to Grassi et al. (2021) in the EU the HWP pool constituted an average sink of 40 Mt CO_2 eq., adding to the average sink of -360 Mt CO_2 in EU forest systems (see Figure 1).



(a) (b)

Figure 1 (a) ***Approximate average net carbon sinks in the EU during 2016-2018 together removing 400 MtCO₂eq/y. (b) The carbon dynamics of the HWP pool in 2018 for the EU (annual sink HWP approx. -33 Mton CO₂/y). (Grassi, G. et al., 2021)***

[9] See e.g. Annex II to the EU LULUCF regulation 2018/841 (https://eur-lex.europa.eu/eli/reg/2018/841/oj) for the definitions used by EU Member States. Often these follows, or are based on, the forest definitions used for reporting to the Food and Agriculture Organisation (FAO) of the United Nations.

[10] The Netherlands for instance reports emissions from peat meadows in organic soils under the Grassland category, while other parties may choose to report these under Wetlands.

Changing the demand towards certain wood products could consequently have an important role in combatting climate change and support the target of climate neutrality. For example, if the woody biomass is used in products with a higher service life (e.g. more production of construction timber instead of paper), if the product replaces fossil and GHG-intensive material or if the by-products (wood waste) is used for energy production. Finding the balance between anthropogenic GHG emissions and GHG removals in the different carbon pools and sinks is essential (UNECE, 2022). Harvested wood products (HWP) pool contributes to tackling climate change through two mechanisms (also see Figure 2):

- forming a carbon storage pool of wood-based products and,
- substituting GHG intensive materials (concrete and streel) and fossil fuels for energy. (The reduction of GHG due to substitution must be reflected in lower GHG emissions of other sectors)

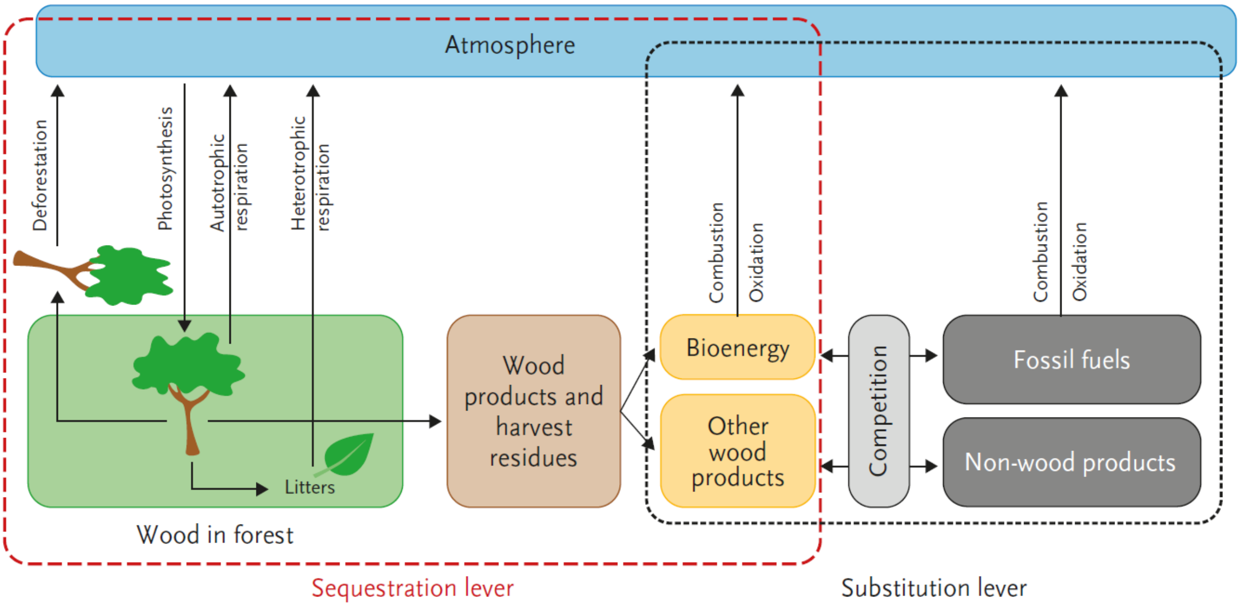


Figure 2 ***Conceptual flow diagram of carbon in a managed forest-wood products-energy chain*** (Nabuurs, 2015). ***The "other wood products" box in the diagram would represent the HWP pool as included under the LULUCF reporting. Carbon in wood used for bioenergy is assumed to oxidise instantaneously.***

According to the 2006 IPCC guidelines, the HWP pool includes all wood material (including bark) that leaves the harvest sites. The wood removal is initially counted as a loss of carbon from the living biomass in the forest land category (4A) and as such counting as a source of CO_2 emissions. Subsequently the carbon is transferred to the HWP pool (4G) where it is counted as a carbon stock gain. The amount of woody biomass that is transferred to the HWP pool is based on production quantities of semi-finished wood products (e.g., sawnwood, wood-based panels and paper and paperboard) reported by the industry in publicly available databases of international organizations such as the Food and Agriculture Organization Corporate Statistical Database (FAO, 2021).

The material left at the harvest sites in forest land are regarded as dead organic matter and are reported in the associated land use category (4A) and not as HWP. Harvested wood biomass, including harvest residues removed from the forest area, used directly as energy and the woody biomass originating from deforestation events do not enter the HWP pool and are reported as an instantaneous emission. The consumption of woody biomass used for energy purposes and its resulting emissions are reported in the Energy sector CRF1 as a memo item. These emissions are not included in the UNFCCC accounting as the emissions are already incurred in the LULUCF sector as a loss of carbon stock in forest biomass.

The IPCC guidelines provide four different approaches for assessing and reporting emissions and removals from HWP at the national level (IPCC, 2006) (IPCC, 2019); the 'stock-change' approach (SC), the 'production' approach (P), 'atmospheric-flow' approach (AF), and 'simple decay' approach (SD). Additionally, 'instantaneous oxidation', which only considers carbon stock losses in forest biomass and no further gains in the HWP pool could be used.

The 'stock-change' and 'production' approaches focus on carbon stock changes within defined HWP pools and derive estimates for CO_2 emissions and removals from these. The 'atmospheric-flow' and 'simple-decay' approaches are based on a conceptual framework that focusses on identifying and tracking CO_2 fluxes.
A further distinction between the approaches can be made based their system boundary definitions and temporal considerations when accounting for emissions and removals (see Table 1). The production approach and simple decay approach both consider all domestically produced HWP within the scope of the methodology for national reporting, also if the wood is exported. These approaches on the other hand exclude imported HWP. The stock change and atmospheric flow approaches consider all domestically used HWP within the scope of the methodology for national reporting. In these approaches imported HWP are included and exported HWP are excluded.

Detailed explanations on the differences are provided in Annex 12A of volume 4 of the 2019 refinements to the 2006 IPCC guidelines.

Table 1 Each HWP approach includes the components with green colour and excludes the components with white colour. (Sato, 2019) and (IPCC, 2019).

HWP Approaches Pool based method	Flux-based method	System boundaries			
Instantaneous oxidation	-	Forest land carbon pool	Domestically produced HWP in use that are consumed domestically	Domestically produced HWP HWP that are exported and in use in other countries	Imported HWP in use
Production approach	Simple decay approach	Forest land carbon pool	Domestically produced HWP in use that are consumed domestically	Domestically produced HWP HWP that are exported and in use in other countries	Imported HWP in use
Stock change approach	Atmospheric flow approach	Forest land carbon pool	Domestically produced HWP in use that are consumed domestically	Domestically produced HWP HWP that are exported and in use in other countries	Imported HWP in use

With these different boundaries and mix of pool based and flux-based approaches there exists a risk of double counting or missing emissions and removals at the international level. To prevent double counting and/or missing emissions and removals the use of the 'production' approach was mandatory for the accounting under the Kyoto Protocol. Under the enhanced transparency framework under the Paris Agreement all parties need to provide the results of applying the 'production approach as common information item to allow for harmonised comparisons among parties preventing double counting. However, for their formal GHG inventories parties may use other approaches. For EU Member states the use of the production approach is mandatory for reporting and accounting under the Paris Agreement as laid down in the EU LULUCF regulation and EU Governance regulation (see Table 2).

Table 2 Summary of HWP treatment under various UNFCCC schemes (Sato, 2019).

Scheme	HWP approach	Applied IPCC guidelines
GHG inventory before Paris Agreement		
For Annex I parties	Production approach, stock-change approach, atmospheric-flow approach, Simple-decay approach	2006 IPCC guidelines
For non-Annex I	No specific rule	Revised 1996 guidelines
Kyoto Protocol		
First commitment period	Instantaneous oxidation	GPG-LULUCF
Second commitment period	Production-based approach/instantaneous oxidation	2006 IPCC Guidelines, 2013 IPCC KYOTO PROTOCOL supplement
Paris Agreement		
GHG Inventory	Production approach (or instantaneous oxidation)—as common information and any approach for national GHG inventory estimation	2006 IPCC Guidelines and any subsequent IPCC guidelines (currently use of 2019 refinement is allowed)
NDC accounting	Any approach. EU Member States need to use the production approach as this is prescribed by the EU Governance regulation and EU LULUCF regulation	IPCC guidance (= all IPCC guidelines and guidance) EU MS: 2006 IPCC guidelines and any subsequent approved IPCC guidelines

Therefore, like all EU Member States, the Netherlands uses the 'Production' approach' and its first order decay methodology to quantify HWP CO_2 fluxes from and to the atmosphere based on the HWP category's half-life times (Arets, E.J.M.M., et al., 2022). This means that the carbon in wood that is harvested from forest in the Netherlands and is used to make products, is removed from the forest land carbon stock and then results in an inflow of carbon into the HWP pool in the year of harvesting. Then in subsequent years the carbon is released again assuming a constant rate of decay from the HWP pool.

The rate of this outflow and emission to the atmosphere depends on the half-life times assumed for the HWP category (see Table 3 for the the default carbon conversion factors and half-lives the Netherlands uses for calculating carbon stock changes from HWP). A half-life of 35 years implies that the amount of carbon remaining in the HWP pool halves every 35 years. That means that after 35 years after the inflow into the HWP pool only 50% still remains in the pool and that after the next 35 years (70 years after inflow) only 50% of this 50% (i.e. 25% of the original carbon inflow remains in the pool and that 75% has been released to the atmosphere again). For products with shorter life spans, and hence half-life times, the carbon stored in HWP is released faster than this. In the case of paper products half of the carbon is released within 2 years, and within 4 years 75% of the carbon is released as CO_2. Figure 3a below illustrates this for an inflow of 1000 tonnes C into the HWP paper category and Figure 3b illustrates the difference in the decay rates between the different HWP categories. Note that this example only gives the carbon development of a onetime carbon input. In reality, every year additional carbon enters the HWP pool from new harvests and products. In the year of inflow this results in carbon gains and the subsequent reduction over time adds to carbon losses in those years.

Table 3 Default carbon conversion factors and half-lives factor for HWP categories (Tier 1) for the Netherlands. These are the default carbon conversion factors and half-lives provided for the different HWP categories in the 2006 IPCC guidelines

HWP category	Carbon conversion factor (Mg C per m3 air dry volume)	Half lives (years)
Sawn wood	0.229	35
Wood based panels	0.269	25
Other industrial roundwood	0.229	35
Paper and paperboard	0.386	2

Harvested wood for fuel is included considering instantaneous oxidation. This means that the carbon in the wood fuel is considered as a loss in forest land biomass and will not enter the HWP pool, which means that is taken as a CO_2 emission from forest land.

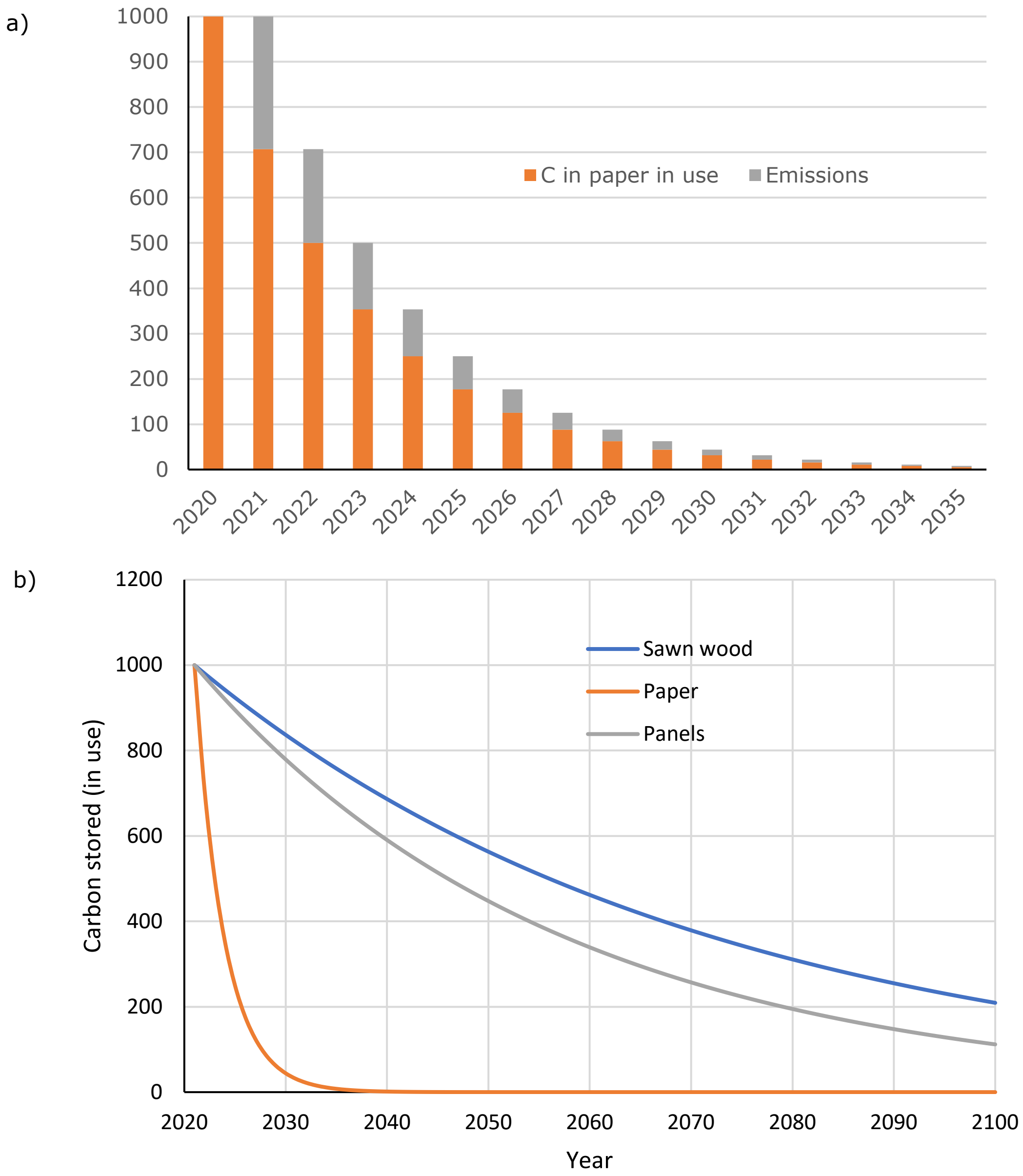


Figure 3 ***a) Decay of an inflow of 1000 tonnes of carbon in 2020 in the HWP paper category with a half-life of 2 years with for every year the amount still in use and the amount emitted; and b) Development of the remaining Carbon stored in HWP (sawnwood, panels and paper) of 1000 tons of carbon entering the HWP pool in 2021 using the first order decay function described in the IPCC guidance in combination with the default half-lives for sawn wood, wood-based panels and paper (See Table 3 above). Note the difference in time on the x-axis.***

A quick review of the methodologies implemented by other EU Member States learns that currently in the EU only France uses national estimates for half-lives, while the other Member States apply these default half-life times of 2 years for paper, 25 years for wood panels and 35 years for sawnwood. As can be inferred from Figure 3, the half-life factors are an important element for determining the emissions and removals from HWP, while at the same time currently most countries, including the Netherlands, use default values for these parameters for assessing emissions and removals for HWP.

This means that currently the climate effects of policies and technological improvements in the wood industry that potentially expand the size of HWP carbon pools[11] are not accounted for in national reporting of GHG emissions and removals. In order to be able to reflect the effects of policies for wood use in the bioeconomy in national greenhouse gas inventories improved country specific information on HWP and their half-life times is required.

Currently only wood products are considered in the national GHG inventories to the UNFCCC. Products made from other biomass sources currently are not included at all in the reporting and accounting system. For use of biobased products that substitute fossil-based products or products associated with large GHG emissions, only this substitution effect is implicitly included in the national GHG inventories. The reason for this omission of other biobased products should be sought in the previous focus on forest related activities in the accounting mechanism under the Kyoto Protocol. Also, in the past there was less focus on other biobased products that could serve as a carbon pool. For instance, the methodological guidelines currently used for reporting are the 2006 IPCC guidelines which have been drafted 16 years ago and have only approved for use in the GHG inventories since 2013.

The European Commission is currently working on proposals for carbon farming, introducing a carbon storage products category for use within the EU climate framework. More information on this is expected to be included in the proposed EU regulation on certification of carbon removals, but the proposal was published too late to be fully considered in the context of this study.

2.2.3 Paris Agreement (PA) – (2015)

The Paris Agreement was adopted in December 2015 under the UNFCCC and entered into force in November 2016 and provides a durable framework guiding the global effort for decades to come and it marks the beginning of a shift towards a net-zero emissions world. Its Parties have agreed to hold the increase in the global average temperature below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1,5 °C above pre-industrial levels. Today, 193 Parties (192 countries plus the European Union) have joined the Paris Agreement. (United Nations, 2021), (IRENA, 2022)

The Paris Agreement requests each country to communicate their post-2020 climate actions in their Nationally Determined Contributions (NDC). The NDC are national plans highlighting climate actions, including targets, policies and measures governments aim to implement in response to climate change and as a contribution to global climate action. NDCs are submitted every five years to the UNFCCC secretariat. Parties are requested to submit the next round of NDCs (new NDCs or updated NDCs) by 2020 and every five years thereafter (e.g. by 2020, 2025, 2030), regardless of their respective implementation time frames. (UNFCCC, 2022)

2.3 The European Union’s commitments under the Paris Agreement Framework

2.3.1 EU emission reporting and accounting

The emission reductions set down in the Paris Agreement (PA) apply to the period 2021–2030. Parties to the PA are required to state their performance targets in Nationally Determined Contributions (NDC). The ultimate goal of the PA is to achieve a balance between greenhouse gas emissions and removals in the second half of this century. The parties to the PA have a certain degree of choice regarding the measures they can adopt to achieve this. Performance will be assessed against the NDC, but again, parties have a certain degree of choice in how they assess and account for the LULUCF sector. EU member states have a joint NDC, the three main elements of which are the EU Emissions Trading Scheme (for energy and heavy industry), the ‘effort sharing’ and LULUCF. In the Effort Sharing Regulation (ESR) the member states have set a common target for the

[11] Like the promotion of use of wood in applications with longer life-times or the implementations of new innovative wood products that promote for instance the utilization of low-quality and small diameter logs, or advance the wood products processing efficiency, develop innovative wood products with longer service life, and/or increase the recycling rates

categories covered, but the allocation of the reductions that need to be made is different for each of the member states on the basis of previously agreed criteria. In 2018 agreements were also made on how the EU member states should account for reductions in greenhouse gas emissions.

Under the EU Green Deal (see section 2.3.2) more ambitious targets have been set and also additional strategies are included that should support the ambition to reach these targets.

2.3.2 The EU Green Deal

The EU Green Deal was launched by the European Commission in December 2019 as the master plan to transform the European Union into a modern, resource-efficient and competitive economy, ensuring: economic growth decoupled from resource use, no person and no place left behind and no net emissions of greenhouse gases by 2050 (European Council-GD, 2022).

Achieving climate neutrality by 2050, requires that current GHG emission levels drop substantially in the next decades and as an intermediate step towards climate neutrality. The European climate law entered into force on July 2021 and sets that the EU has raised its 2030 climate ambition, committing to cut net emissions by at **least 55% by 2030**. This target is in line with the Paris Agreement objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it to 1.5°C.

To turn the European Climate Law ambition into reality, the current European laws require structural adjustments therefore the '**Fit for 55' package** was created (September 2020). (European Comission, 2021) This package set proposals to revise and update EU legislation and to put in place new initiatives to ensuring that EU policies are in line with the climate and energy goals agreed by the Council and the European Parliament.

The "Fit for 55 Package" covers everything from renewables to energy efficiency, energy taxation, new buildings, as well as agriculture, forestry, land use and land use change, effort sharing and emissions trading and a wide range of other pieces of legislation.

Other Commission initiatives that have strong interlinkages with the EU Green Deal on protecting and improving the resilience of the EU's forests to climate change, are:

- EU Biodiversity Strategy for 2030. (European Commission-BDS, 2022)
- Farm to Fork Strategy. (European Commision-F2F, 2020)
- Carbon Farming Initiative. (European comission-CFI, 2021)
- EU Forest Strategy 2030. (European Parliamentary Research Service, 2022)
- EU Strategy on Adaptation to Climate Change. (European Commisson- ACC, 2021)
- EU Strategy to Reduce Methane Emissions. (European Commission-RME, 2020)
- EU Soil Strategy. (European Commission-SS, 2021)
- Zero Pollution Action Plan. (European Commission-ZPAP, 2021)
- EU action plan for the Circular Economy (CEAP) II. (European Commission-CEAP, 2022)
- Proposal for a Regulation on Ecodesign for Sustainable Products. (European Commission-ED, 2022)
- The new common agricultural policy: 2023-27. (European Commission-CAP, 2021)
- Clean Energy Strategy. (European Commision-CEE, 2022)

For the LULUCF sector in the European Union, the initial regulatory framework was laid down in **Regulation (EU) 2018/841** (2018) as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and the regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. The regulations set out the commitments of the Member States for the LULUCF sector that contribute to achieving the objectives of the Paris Agreement and meeting GHG emission reduction target for the EU for the period 2021-2030. It also lays down rules for the accounting of emissions and removals from LULUCF and for checking compliance of Member States. These regulations contribute to the previous Union's emission reduction target of at least 40% by 2030 compared to 1990. (European Commission, 2018)

The LULUCF sector is connected to all ecosystems and economic activities that rely on the land and the services it provides. Therefore, the LULUCF Regulation presents synergies with other EU policies that cover land-related activities, mainly the Common Agricultural Policy and the energy policy, particularly in respect of renewable energy.

The proposal to amend Regulation (EU) 2018/841 as part of the 'Fit for 55' package aims to strengthen the contribution of the LULUCF sector to the increased climate ambition for 2030 and to reverse the current declining trend of carbon removals and enhance the natural carbon sink throughout the EU. Specifically, the revision of the current legislation proposes to:

- set an EU-level target for net removals of GHG of at least 310 million tonnes of CO_2 equivalent by 2030, which is distributed among the member states as binding targets.
- simplify the rules on accounting and compliance and enhance monitoring

On 29th of June 2022, the proposals of the European Parliament and of the Council for the review and amend of the Regulation (EU) 2018/841 and Regulation (EU) 2018/1999, as part of the 'Fit for 55' package (A9-0161-2022) were adopted as negotiation position in the trilogues. This amendment covers some aspects related to the use forestry and agricultural biomass in long lasting biobased products which will be discussed in more detail in section 3.

2.3.3 EU Sustainable Carbon Cycles and Carbon farming

Under the EU Green deal, in December 2021 the EU commission communicated its approach for sustainable carbon cycles. (European commision-SCC, 2022). This covers all aspects (e.g. reducing, recycling, reusing) of decoupling production systems from fossil based carbon and shifting towards renewable and biobased carbon sources. A key element of this approach is Carbon farming. Carbon farming is seen to play a very important role in the EU meeting its climate change targets. It is currently an area of much interest, with the European council releasing a proposal for EU certification for carbon removals in November 2022 (European Commission - Press release, 2022). For the purpose of this report, we will focus on the relevant elements of carbon farming for the material transition.

"Carbon farming can be defined as a green business model that rewards land managers for taking up improved land management practices, resulting in the increase of carbon sequestration in living biomass, dead organic matter and soils by enhancing carbon capture and/or reducing the release of carbon to the atmosphere, in respect of ecological principles favorable to biodiversity and the natural capital overall" (European Commision-CF, 2021)".

The EU aims to have access to verified emissions and removal data for all land managers by 2028 and by 2030 it aims to contribute to reaching the LULUCF target of 310Mt CO_{2eq}[12] removals. For this the EU's action plan is composed of several activities to support carbon farming, while also gathering the necessary information to develop appropriate infrastructures to ensure appropriate MRV (monitoring, reporting, validation) of any carbon farming initiatives operating in the EU. Examples of these activities include: 1) funding for current and future EU projects in relation to carbon farming,2) an ongoing project looking into the "polluter pays principle" and 3) a carbon farming expert group to provide advice on how to set up (in detail) a certificate system for carbon removals. (Forlin V. DG CLIMA, 2022).

The Commission, supported by the expert group will develop the certification methods for carbon removals. The proposal for establishing a certification framework for carbon removals aims to ensure the transparency and credibility of the certification process. It aims to do this by setting out rules for: 1) the independent verification of carbon removals and 2) the recognition of certification schemes that can be used to demonstrate

[12] Carbon dioxide equivalent (CO_2eq) stands for a unit based on the global warming potential (GWP) of different greenhouse gases. The CO_2eq unit measures the environmental impact of one tonne of these greenhouse gases in comparison to the impact of one tonne of CO_2.

compliance with the EU framework. Furthermore, the need to ensure the quality and comparability of carbon removals is paramount, therefore, the proposed regulation establishes four QU.A.L.ITY criteria:
1.Quantification: Carbon removal activities need to be measured accurately and deliver unambiguous benefits for the climate.
2.Additionality: Carbon removal activities need to go beyond existing practices and what is required by law.
3.Long-term storage: Certificates are linked to the duration of carbon storage so as to ensure permanent storage.
4.Sustainability: Carbon removal activities must preserve or contribute to sustainability objectives such as climate change adaptation, circular economy, water and marine resources, and biodiversity

In addition to these criteria the regulation also aims to enhance the uptake of market-based carbon removal solutions. It is also recognized that to meet all of these requirements there will be the need the establishment an effective governance framework for effective, cost efficient and transparent implementation.

Currently the carbon market has two major types of schemes in place. The Activity based carbon farming schemes where payments are made if defined carbon farming measures are implemented (independent of the resulting impact of those measures). The Results- based carbon farming: Paying for reduced net GHG fluxes from a carbon farmer's land (e.g. sequestering carbon), there needs to be a direct link between results delivered and payment. (Thorsøe, 2022)

Delving further into the design of these schemes, to date there seems to be 3 design options in play, which relate primarily to the funder of the certificates. The first is the direct farm payments to the landowner or farmer through the CAP pillar of the European Agricultural Fund for Rural Development (EAFRD) fund. The second is through insetting[13] of emissions along the Agri-food company supply chain (Di Virgilio N.-DG AGRI, 2022). The last are the voluntary carbon markets, in which private companies trade certified carbon credits between farmers and other sectors/industries looking to offset their GHG emissions. For the EU commission, to avoid potential conflict between private and public (EU funded) payments the proposal is that each carbon credit would be give a unique identifier code when registered in the EU registry for carbon credits. That way such a credit can only be traded once. This would ensure that no double payments are made, but also to track the emissions traded, to also prevent from double accounting between different NIR (national emission inventory reporting) sectors.

Currently, there are many challenges faced in rolling out an effective carbon credit scheme that can be monitored robustly, reported transparently and validated effectively. However, there is a lot of on-going work currently being done at the EU level to try and find solutions to these many challenges. The publishing of the proposal for establishing a framework is a major step in accelerating the identification of potential solutions.

2.4 Differences between the reporting-accounting methods

Under the UNFCCC reporting of greenhouse gas emissions and removals, parties report on human induced emissions and removals. As part of the agreements under the Kyoto Protocol, and now under the Paris Agreement additional targets for emission reductions and increasing removals of CO_2 have been agreed. For the Paris Agreement these party specific targets are laid down in the Nationally Determined Contributions. For most emission sectors the targets set a certain (relative) emission reduction against the emissions in a base year, usually 1990. Since the second commitment period under the Kyoto Protocol will see its final end-term accounting in 2022, we will not provide detailed information on the principles of Kyoto Protocol accounting. Detailed information can be found in Iversen et al, 2014 (Iversen P., 2014) and (Hendriks, 2021). It applied different accounting rules for different land-use activities that were not necessarily one-to-one based on the UNFCCC land-use categories. Final accounting of the second commitment period of the Kyoto Protocol is based on the accounting values reported in the NIR 2022. Only forest related activities (afforestation/reforestation, deforestation and forest management were mandatory included in the accounting. The other activities could

[13] Insetting projects are interventions along a company's value chain that are designed to generate GHG emissions reductions and carbon storage, and at the same time create positive impacts for communities, landscapes and ecosystems. (IPI, 2022)

be included in the accounting on a voluntary basis, but this had to be communicated before the start of the second commitment period. Figure 4. gives an overview of the reporting and accounting provisions.

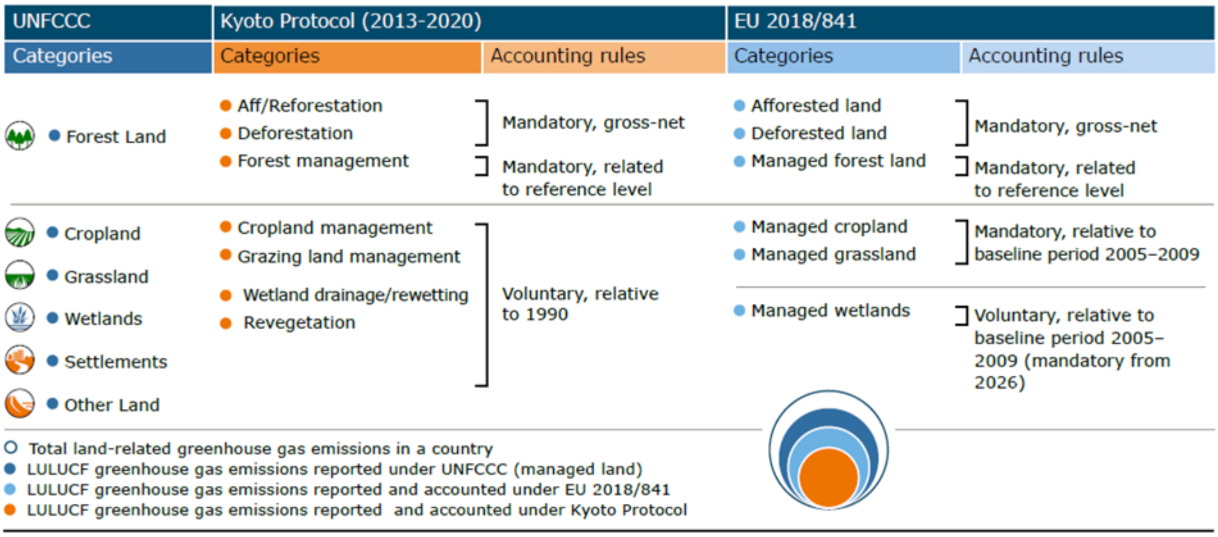


Figure 4 Overview of the reporting obligations (UNFCCC) and accounting provisions under the 2nd commitment period of the Kyoto Protocol and according to the EU LULUCF regulation (before the amendment was proposed – this needs an update now the amendments have been agreed on by the Commission, EU Parliament, and EU Council).

Under accounting for the Paris Agreement, the EU LULUCF regulation again identifies different accounting categories with different accounting rules. The advantage compared to the accounting categories used under the Kyoto Protocol is that now the accounting categories are directly based on the UNFCCC land use categories (Hendriks, 2021). Afforested and deforested land (Article 6) is accounted for gross-net: total emissions and removals for the periods 2021-2025 and 2026-2030 are included. Managed cropland, grassland and wetland (Article 7) are accounted for net-net: emissions and removals for the two periods minus five times the value of average annual emissions in the base period (2005-2007). Managed forest land, including harvested wood products (Article 8) is accounted for as the emissions and removals for the two periods minus five times the Member State's Forest reference level. This Forest Reference Level (FRL) is an estimate of CO_2 removals (by carbon sequestration in forests). It takes account of age-related growth of the existing forest on the assumption that the forest management regime is a continuation of the management during the historical reference period (2000–2009). The FRL and supporting argument description of its determination is set down in a National Forestry Accounting Plan (NFAP). The use of the FRL provides some degree of guarantee that only additional mitigation efforts by MS are considered in the accounted removals and that the removals that are pure the result of 'business as usual' forest growth, management and harvesting are not rewarded.

2.5 The Netherlands (National Framework): The Dutch Climate Agreement

The Dutch Climate Agreement (Het Klimaatakkoord) was concluded between more than 100 civil society parties (both public and private) and contains a package of measures to actively support the main goal to achieve a 49% reduction in national greenhouse gas emissions by 2030 compared to 1990 levels. (Goverment of the Netherlands, 2019). The Climate Agreement has 5 sector platforms (C1) Built environment, (C2) Mobility, (C3) Industry, (C4) Agriculture and land use and (C5) Electricity. Each one with specific targets that are not only based on a cost-effective measure until 2030, but also consider the desirability of longer-term measures to aid transition until 2050.

The Dutch Climate Agreement consists mainly of 3 parts:[14]

- Part B, outlines the goals and targets of the Dutch Climate Agreement and sets out the principles for monitoring and governance.
- Part C, contains the commitments made in five sector platforms.
- Part D, contains the agreements that were made regarding issues that affect multiple sectors. These agreements cover the following ten topics: (D1) Systems integration, (D2) Biomass, (D3) Integrated knowledge and innovation agenda, (D4) Labour market and training, (D5) Creating support in society, (D6) Spatial task, (D7) Regional Energy Strategies, (D8) Opportunities for market financing, (D9) Key principles for the expansion of the SDE+ scheme, (D10) The exemplary role of the national government.

In 1990, total GHG emissions in the Netherlands were approximately 228 million tons of CO_2 (all other GHG such as methane and nitrous oxide are recalculated to CO_2 equivalents). In 2030, those emissions must be 49% lower, which is 116 Mton CO_2. Without the Dutch Climate Agreement, emissions in 2030 would amount to 165 Mton CO_2. The Dutch Climate Agreement must therefore, ensure a reduction of 49 Mton greenhouse gases by the year 2030. The commitments per sector platform for 2030 in the Dutch Climate Agreement are shown in Figure 5.

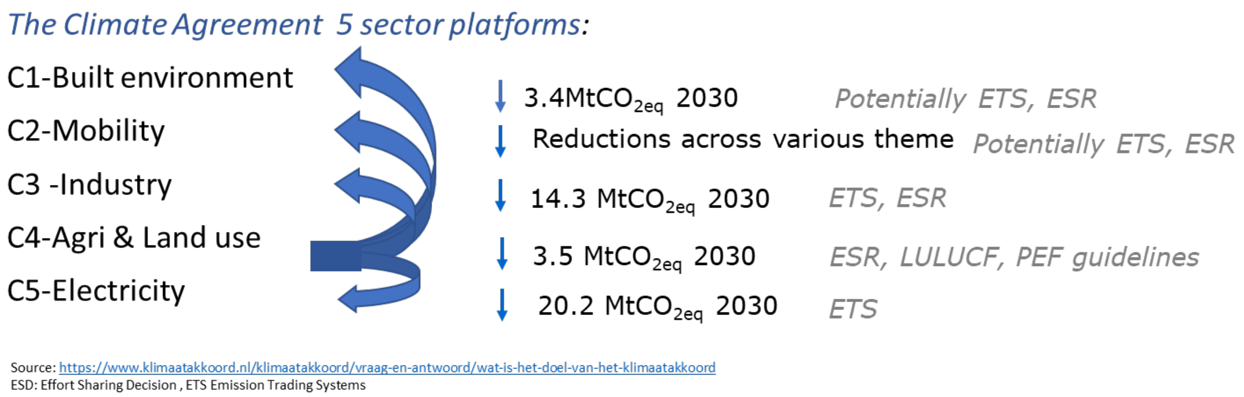


Figure 5 The Dutch Climate Agreement targets 2030 per sector platform (-49 Mton CO_2eq).

Sector C4. Agriculture and land use is a relevant provider of raw materials to produce biobased products. The commitments in this sector are focus on the transition towards nature-inclusive and circular agriculture. As for livestock farming, efforts will concentrate on making stables emission-free, making changes to animal feed and improving the processing of manure. In the greenhouse horticulture sector, work will continue achieving energy savings, generating sustainable energy and using heating and CO_2 provided by third parties. Efforts will also be made to change the behavioural patterns of food consumers to reduce food wastage and increase the uptake of more sustainable, plant-based foods. Smart solutions regarding land use, including pilot projects to raise the water level in peat meadow areas. In addition, various measures will be introduced that will contribute to increased carbon capture over time. This includes expansion of the natural area, restore landscape structures, limit deforestation, lead to the planting of new trees and increase carbon capture in agricultural soils through smart and sustainable use. However, within sector C4 more clarity is needed on:

- How to enhance the distribution, use and application of biomass?
- How to calculate the reduction of GHG due to substitution of fossil-based products by biobased products in other sectors?

Additionally, a 'National Biomass Roadmap' is mentioned (C.4.3.5), this document was published in June 2020 and try to outline the quantities of biomass that could be available as feedstock for high grade use such biobased materials with a long-term carbon storage and chemicals. According to the roadmap, the availability of Dutch bio-based raw materials can grow considerably. However, collaboration between government and industry is crucial. The industry's demand for raw materials must be clear before the production of bio-raw materials can increase.

[14] Part A is small introduction to the document.

The Dutch government is convinced that the use of biomass is crucial for the sustainability of the national economy and the realisation of the climate targets toward 2030 and 2050. Therefore, it is important to note that in the Dutch Climate Agreement, section D2. Biomass, it is mentioned that the sustainability criteria to prioritize applications, applied cascading and consider potential flows of biomass to the most relevant sectors are still being developed. In the long term the parties (government, nature managers, NGO's and industries) aim to use sustainable biomass for high grade applications in commercial sectors where there are few alternatives for feedstock.

2.6 Product level - Relevant standards and guidelines on biogenic carbon accounting

For the calculation of life cycle GHG emissions of biobased products, there are specific considerations required for the accounting of biogenic carbon uptake during biomass growth and releases during the product life cycle, as well as for the accounting of any form of temporary or "permanent" (long-term) storage of biogenic carbon in products. This section focuses on evaluating how methodological aspects relevant for biogenic carbon are dealt with in life cycle analysis (LCA) standards and guidelines.

Accounting of biogenic carbon (uptake and release)
Biogenic carbon is the carbon that is stored in biological materials. Biogenic carbon can be captured as CO_2 from the atmosphere through photosynthesis during biomass growth, a process commonly referred to as sequestration. Biogenic carbon can then be emitted to air as CO_2, CO or CH_4 as a result of the oxidation and/or reduction of biomass by means of its transformation or degradation (e.g. combustion, digestion, composting, landfilling) (Breton C., 2018), (Hoxha, E., A. et al., 2020).

In traditional LCAs, two main approaches can be distinguished when assessing the impact of biogenic carbon uptake and release. The first approach, which is referred to as the '0/0 approach' or 'carbon neutral approach', assumes that the release of CO_2 from a bio-based product at the end of its life is balanced by the uptake of CO_2 during the biomass growth (Hoxha, E., A. et al., 2020). Consequently, there is no accounting of biogenic CO_2 uptake or release. The neutral approach (0/0) may be applicable for energetic use of biomass where all the carbon sequestered is released by incineration.

The second approach, which is referred to as the '−1/+1' approach, consists of tracking all biogenic carbon flows over the product life cycle (Hoxha, E., A. et al., 2020). In this approach both biogenic CO_2 uptake (−1) and release (+1) are considered. The main advantage of the −1/+1 approach is the increased transparency of the biogenic carbon flows throughout the life cycle.

For biobased products the situation is more complicated. The biogenic carbon can be stored for longer time in products and incineration is not the only end of life option. In the end of life biogenic carbon can be emitted in the form of CO_2 if fully oxidized or partially oxidized and form CO and/or CH_4. The biogenic carbon can also flow into other products by recycling. A review is made below on the approaches recommended for accounting for the biogenic carbon in biobased products by relevant standards and guides on life cycle analysis (LCA) and carbon footprint.

Delayed emissions - Temporary or permanent biogenic carbon storage
Besides the assessment of biogenic carbon uptake and release, another point of consideration is the assessment of the effect of biogenic carbon storage. Carbon storage can be defined as the sequestration of carbon in products for a certain period of time resulting in a (temporary) reduction of the CO_2 concentration in the atmosphere (Brandão et al. 2013). The application of biobased products has the potential to (win time to) mitigate climate change, even if the carbon storage and associated benefits might be temporary. For the duration of storage, the CO_2 is not exerting a radiative forcing, i.e. it does not exert a global warming potential effect. The biogenic carbon is kept stored for a certain amount of time that delays radiative forcing. A distinction is made between carbon that is released within a short-term (temporary storage) and long-term (beyond a longer and specified time-horizon set by convention, and which is then considered as "permanent" storage).

To account for the benefit of delayed emissions, several approaches have been proposed. The achievable benefits from accounting for biogenic carbon storage depend on the time horizon over which the global warming potential of emissions is considered, as well as external factors such as the future levels of anthropogenic GHG emissions and atmospheric CO_2 and CH_4 concentrations and the saturation of the different sinks (e.g. oceans, land). This is a highly debated and controversial topic and therefore in current standards and guidelines, accounting for potential benefits due to biogenic carbon storage is not allowed. Some consider their reporting separately. Further information is provided in the review below.

There are several standards and guidelines available related to LCA and carbon footprint of products as listed in Table 4. They are based on the International Standards on LCA (ISO 14040 and ISO 14044). The last two are specific for the construction products (ISO, 2006).

Table 4 Reviewed standards and guidelines.

Name of standard/guideline	Short description
ISO 14067:2018 Greenhouse gases – Carbon Footprint of products– Requirements and guidelines for quantification. (ISO, 2018)	This international standard specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product (CFP), This document addresses only a single impact category: climate change.
EN 16760:2015 Biobased products – Life Cycle Assessment. (European Standard EN 16760, 2015)	This European Standard provides guidance and requirements to assess impact over the life cycle of biobased products excluding food, feed and energy, with the focus on how to handle the specificities of the biobased part of the product.
Product Environmental Footprint (PEF) guide, 2013. (European Commission PEF, 2013), (Zampori L. and Pant R., 2019)	The PEF guide developed by the Directorate General Joint Research Centre (JRC) of the European Commission (EC), provides a harmonised methodology for the calculation of a product environmental footprint. PEF guide provides detailed and comprehensive technical guidance on how to conduct a PEF study, as well as how to create product category-specific methodological requirements for use in Product Environmental Footprint Category Rules (PEFCRs). (European Commision, 2018)
PAS 2050, 2011 - Specification for the assessment of the life cycle GHG emissions of goods and services. (British Standards Institution (BSI)., 2011)	PAS 2050 developed by the British Standards Institution (BSI) aim to provide a consistent, internationally applicable method for assessing the life cycle of GHG emissions of goods and services. Organisations can use this standard to assess the climate change impact of the goods and services they offer.
GHG Protocol, 2011 - Product Life Cycle Accounting and Reporting Standard. (Greenhouse Gas (GHG) Protocol, 2011)	The GHG Protocol Product Standard is one of a suite of accounting tools developed by the GHG Protocol to encourage users to understand, quantify, and manage GHG emissions. It provides requirements and guidance for companies and other organizations to publicly report GHG emissions associated with a specific product.
ILCD Handbook, 2010. (European Commission- JRC, 2010)	ILCD Handbook provides technical guidance for detailed LCA studies and provides the technical basis to derive product-specific criteria, guides, and simplified tools. The overall objective of the ILCD Handbook is to provide a common basis for consistent and quality-assured life cycle data and robust studies.
ISO 21930:2017. Sustainability in buildings and civil engineering works. (ISO, 2017)	This global standard provides the principles, specifications and requirements to develop an environmental product declaration (EPD) for construction products and services, construction elements and integrated technical systems used in any type of construction works.
EN 15804:2019 Sustainability of construction works—Environmental product declarations. (European Standard EN-15804, 2019)	This European standard provides core product category rules (PCR) for environmental product declarations for any construction product and construction service.

2.6.1 Review of standards and guidelines concerning biogenic carbon accounting

There is currently no consensus across these different standards and guidelines on how to handle biogenic carbon emissions and removals from products and any resulting storage of biogenic carbon. An overview of the biogenic carbon accounting approaches adopted in these relevant standards and guidelines, and their key aspects, is presented in Table 5 and will be explained in this section.

Table 5 Overview of key aspects of approaches for biogenic carbon accounting adopted in relevant standards and guidelines.

	Key aspect	ISO 14067	EN 16760	PEF	PAS 2050	GHG Protocol	ILCD Handbook	ISO 21930 EN 15804
1	Accounting of biogenic carbon (uptake and release)							
	Biogenic carbon removals and emissions to be included in the inventory/modelling	Yes	Yes	Yes ([a])	Yes, except for food and feed	Yes	Yes	Yes
	Impact assessment of biogenic carbon emissions and removals	CFs = -1/+1	CFs may be either set to -1/+1 or 0/0	CFs = 0/0	n.s. (-1/+1) ([b])	CFs = -1/+1	CFs = -1/+1	CFs = -1/+1
	Biogenic carbon removals and emissions to be reported (or inventoried) separately	Yes	Yes	Yes ([c])	n.s.	Yes	Yes	Yes
2	Delayed emissions due to temporary carbon storage							
	Delayed emissions due to temporary carbon storage included in the assessment	No, can be reported separately, a minimum storage time of 10 years is considered.	No, should be taken into account where relevant but reported separately.	No	No, can be reported separately together with the main results	No, can be reported separately.	No, can be taken into account if directly required in the goal of the study.	No, ISO 21930 state can be reported separately.
	Calculation method for including the effect of delayed emissions specified	No	Yes, the calculation method specified in the ILCD Handbook may be followed.	No	Yes	No	Yes	No
3	Delayed emissions due to 'permanent' carbon storage							
	"Permanent" carbon storage included in the assessment	n.s. ([d])	No, can be reported separately.	No	Yes, carbon storage of >100 years is considered permanent	Yes, a minimum time period of 100 years considered. ([e])	Yes, inventoried separately using 100 years time-frame; emissions occurring after 100,000 years not accounted	No

Notes: n.s. = not specified
([a]) Unless a simplified modelling approach (where only biogenic CH_4 emissions are modelled) is selected in a specific PEFCR.
([b]) Not explicitly reported in the standard, but it can be inferred from provisions related to other relevant aspects.
([c]) The provision in the PEF method refers to the modelling, not to the reporting. Biogenic carbon emissions and removals shall be modelled separately in the inventory, but not reported (separately) in the PEF results. This applies unless a simplified modelling approach is selected in a specific PEFCR.
([d]) The standard does not report any specific time horizon (or assessment period) after which carbon removed from the atmosphere (e.g. during biomass growth) shall be considered as no longer released, and hence as "permanently" stored. It may hence be inferred that no permanent carbon storage shall be accounted in the assessment.
([e]) Companies shall report the time period of the inventory. Companies shall report the amount of carbon contained in the product or its components that is not released to the atmosphere during waste treatment and therefore is considered stored.

Accounting of biogenic carbon (uptake and release)

Most standards and guidelines (i.e. ISO 14067, PAS 2050, GHG Protocol, ILCD Handbook, ISO 21930 and EN 15804) explicitly or implicitly consider the -1/+1 approach (Hoxha, E., A. et al., 2020), which implies tracking all biogenic carbon flows over the life-cycle, to be then characterised with characterisation factors equalling -1 for CO_2 removals and +1 for CO_2 emissions. The PEF method also makes an inventory of biogenic carbon removals and emissions but applies the 0/0 approach (as CFs for biogenic CO_2 uptakes and releases are set to zero). EN 16760:2015 allows both approaches to be chosen. EN 16760 also specifies that a simplified approach may be used to determine the net quantity of atmospheric carbon dioxide fixed in a product, based on stoichiometry or the biogenic carbon content of the product itself.

All standards and guidelines (including PEF) require reporting (or inventory) separately the biogenic carbon removals and emissions.

Delayed emissions due to temporary carbon storage

Regarding temporary carbon storage and resulting delayed carbon emissions, none of the LCA standards and guidelines consider including effects from any delayed emissions due to temporary carbon storage. If relevant, some guidelines allow such effects to be documented separately, but not included in the carbon footprint. ISO 14067 prescribes that GHG emissions and removals shall be modelled as if released or removed at the beginning of the assessment period, i.e. at the same point in time, therefore not to be included in the calculation of the carbon footprint. If quantified, such effects are to be documented separately. Additionally, in ISO 14067 a minimum storage time of 10 years is considered. No minimum storage time is specified in other standards or guidelines. EN 16760, prescribes that where temporal accounting of GHG emissions is relevant (due to e.g., temporary carbon storage), it can be reported separately. An example of such a calculation method is provided (in Annex B.3 of the standard), which is based on discounting of emissions over a 100-year timeframe, as specified in the ILCD guidance. PAS 2050 also considers a time frame of 100 years to evaluate GHG emissions from products. Any evaluation of the effects of delayed emissions is to be conducted separately. A specific quantification approach is prescribed for this (Annex E to the standard). Regarding temporary carbon storage and delayed emissions, ISO 21930 states that "*several methodological approaches have been proposed to address delayed emissions in the quantification of the Global Warming Potential - GWP, for example approaches based on discounting or approaches based on time-dependent characterization factors within a predefined reference study period. Since there is no common acceptance of these approaches, such calculations are not part of the quantification of the GWP. If a manufacturer wishes to declare quantitative or qualitative information on delayed emissions within the Environmental Product Declaration - EPD, the information shall be reported under "Additional environmental information not derived from LCA" and the underlying methodology shall be referenced".* EN 15804 is aligned with PEF, where no permanent and/or temporary carbon storage can be accounted for, nor reported as additional information.

Delayed emissions due to 'permanent' carbon storage

PAS 2050 explicitly specifies that the portion of removed carbon not emitted to the atmosphere during the default 100-year assessment period is to be treated as if it was no longer released back to the atmosphere (i.e. as "permanently" stored carbon). Apart from PAS 2050, none of the mentioned standards explicitly specify a fixed time horizon (or assessment period) after which carbon removed from the atmosphere (e.g. during biomass growth) is to be considered as no longer released, and hence as "permanently" stored. ILCD Handbook separately inventories delayed emissions beyond 100 years as 'Carbon dioxide, biogenic (long term)'.

New European standard for guidance on comparative LCAs

European Committee for Standardization (CEN) Technical Committee TC411 Bio-based products, working group 4 "Sustainability criteria, life cycle analysis and related issues" is currently working on a new European standard concerning comparative LCAs for bio-based products with their fossil-based counterparts. This standard "Bio-based Products – Life Cycle Assessment - Additional requirements and guidelines for comparing the life cycles of bio-based products with their fossil-based equivalents" is needed to bring harmonization and prevent an unlevel playing field between fossil and biobased products. The EU Taxonomy Regulation requires LCA performance needs to be demonstrated for biobased products to be considered as being environmentally preferable to fossil alternatives for which this standard would be highly relevant. This standard will cover among others the topics of accounting of biogenic carbon and delayed emissions.

2.6.2 Dynamic LCA

One of the biggest challenges for LCA with regards to carbon storage in biobased products is the consideration and inclusion of time. In scientific literature, to better capture the impact of time, dynamic approaches have been developed which considers use of time dependent characterization factors for the calculation of global warming potential (GWP). (Breton C., 2018), (Hoxha, E., A. et al., 2020), (Levasseur, A., et al., 2010)

Breton et al. (2018) and Hoxha et al. (2020) provide very comprehensive reviews of the current LCA approaches for considering the temporal scope of biobased products. Hoxha et al. (2020) identified the dynamic approach of Levasseur et al. (2010) to be the most pertinent approach (DLCA), whereas Breton et al. (2018) identified both the dynamic approach of Levasseur et al. (2010) and the approach of Cherubini et al. (2011) GWP_{bio} as the two most promising methods to use. (Cherubini, F., et al., 2011) The underlying computational framework of both approaches is based on the IPCC metrics relating to GWP and estimates of radiative forcing and atmospheric rates of decay. Cherubini et al. (2011), focuses on accounting for the biogenic flows of carbon in biobased products only allowing for the inclusion of biomass rotation times for carbon storage, whereas the approach of Levasseur et al. (2010), allows for consideration of both biogenic and non-biogenic carbon flows in the system modelled. The disadvantage to both approaches is that they are quite complex to compute and time consuming. The dynamic life cycle inventory data is distributed over time, which requires tracking all emissions and removals for all GHGs and for every year over the life cycle. Recently, discussions have taken place in France on the issue of integrating, a dynamic GWP indicator in the 2020 regulation (RE2020) on new buildings. At the request of the French Minister of Ecological Transition, discussions to produce a standard on a dynamic GWP indicator could be launched at European level. The dynamic indicator proposed by the French regulation is a simplified approach of the dynamic LCA method of Levasseur et al. (2010) by the application of a time dependent correction factor to convert to a static indicator. (Ventura, A., 2022)

2.7 GHG accounting perspectives

After the preceding sections, we can summarize that there are two major scales of reference for accounting. These approaches have different perspectives (see Figure 6):

- Product accounting level: embodied carbon through the life-cycle of the biobased material. Generally, not looking at the timing of the carbon fluxes, temporary biogenic carbon storage in the soil and product or where emissions take place. In many cases biomass is assumed carbon neutral.
- National inventory accounting: country emissions and removals, including carbon soil sink, HWP carbon pool and considering, semi-finished products half-lives.

In the product accounting, the life cycle GHG accounting evaluates and reports the GHG emissions associated with the raw materials extraction, manufacturing or processing, transportation, use, and end of life management of a product or service. A life-cycle perspective accounts for all emissions connected to the product or service, regardless of which industrial, economic activities or sectors produce these emissions (e.g., energy, mining, transport, manufacturing, or waste sectors) or where and when these benefits or burdens occur over time. In other words, life cycle assessment is designed to be a global assessment tool, as all emissions are aggregated together for the full life cycle removing any spatial or temporal details relating to the production or distribution of impacts. (O'Keeffe, S., et al., 2016)

In contrast to the product level accounting perspective, GHG national accounting or national inventories identify and quantify human-caused sources and sinks of GHG in order to develop an accounting of overall GHG emissions for a specific entity (e.g. industry, region, community, or nation). The GHG inventories are used to establish baselines, track GHG emissions, and measure reductions over time for that entity. The perspective of inventories depends on the timeframe used to evaluate GHG emissions. In some cases, inventories may offer a narrower accounting of GHG emissions. For instance, an annual inventory that includes emissions associated with producing materials may not also include emissions associated with managing that material at end-of-life given that the material may still be in use. This prevents decision-makers from using inventories to assess the full life-cycle benefits of materials management options. The fundamental difference is that the national accounting approaches quantify GHG emissions from different industrial or economic sectors and regions or countries on an annual basis (EPA, 2016) , they are disaggregated.

Additionally, there are initiatives like Carbon Farming Framework or the recently proposed Carbon Removal Certification Framework that could play a role in both accounting levels. For carbon farming, tracking a farm's carbon footprint and switching to sustainable agricultural practices that enhance soil to store carbon more probably will have a strong influence on product accounting. However, this information will be used to estimate the sequestration potential of areas of the farms devoted to, for example, grassland or agroforestry production, helping to estimate the carbon credits or certificates for the farmer or landowner. The EU is hoping to do two things:

- In the short term - make sure there is no double accounting between sectors (at national level or interference with international mechanisms)
- In the long term - use it to improve their national inventory reporting.

In this is the case, there will be a connection to reporting at the EU level towards meeting CAP and Green deal targets (Forlin V. DG CLIMA, 2022).

Regarding the Carbon Removal Certification Framework, this framework promotes a first EU-wide voluntary framework to reliably certify high-quality carbon removals. The proposal intent to boost innovative carbon removal technologies and sustainable carbon farming solutions, and contribute to the EU's climate, environmental and zero-pollution goals. (European Commission - Press release, 2022)

The removal, storage and recycling of carbon dioxide are key aspects of this proposal where various solutions, both technology- and nature-based, are considered and the challenge will be to ensure permanence of carbon dioxide removals, whether in underground geological storage or through actively managed natural processes, such as carbon farming and management practices in the land use, land-use change and forestry sectors. The Commission therefore aims to push for product and process innovation to substitute current fossil-based feedstock with sustainably sourced bio-based materials, or through the circular economy, to ensure that carbon integrated in products is recycled and remains stored.

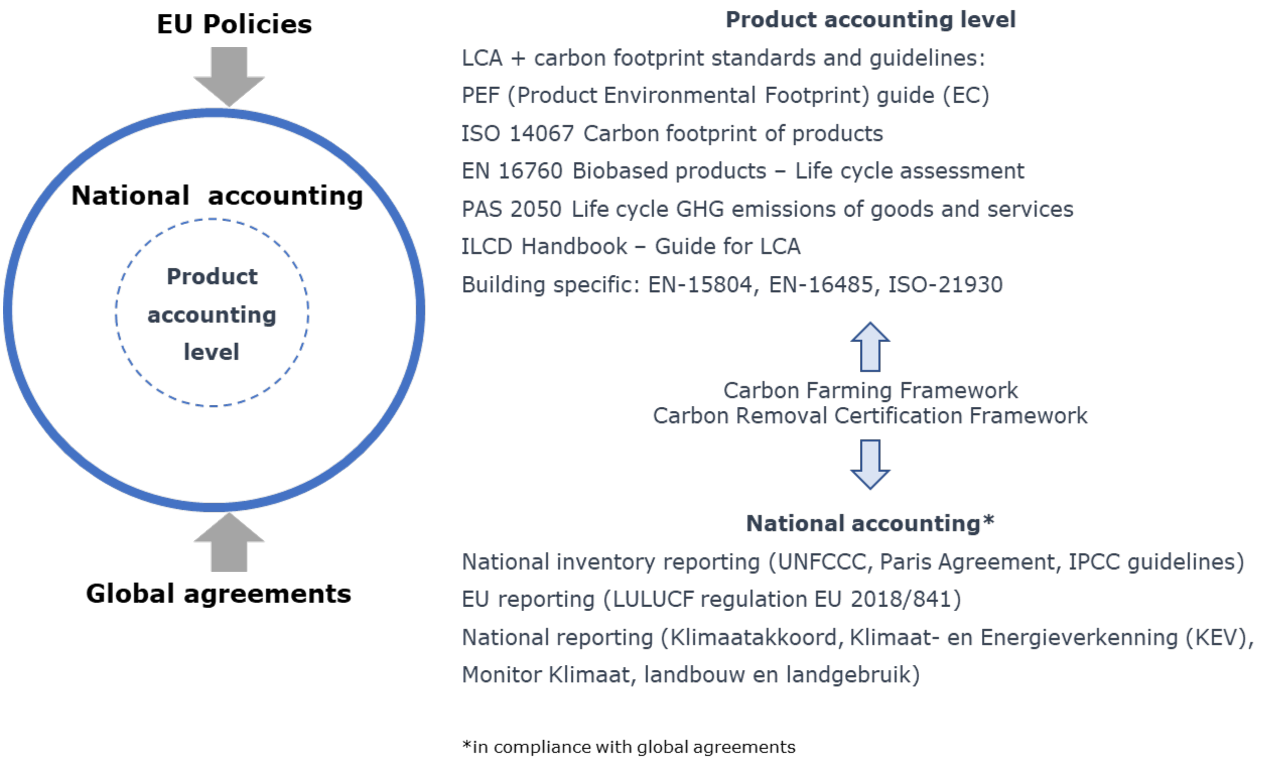


Figure 6 Two different approaches of GHG accounting: Product and National Level accounting.

3 Role of biobased products in meeting Climate Targets

Bioeconomy can contribute to climate change mitigation by: (Grassi, G. et al., 2021):

1. Increasing carbon stocks (creating a 'net sink' for CO_2):
    a. In the forest or agricultural land as carbon stocks of pools (sequestration);
    b. In the HWP or Carbon Storage Products pool (storage);
2. Substitution effects (preventing the release of GHGs), i.e. using wood to replace:
    a. Functionally equivalent materials (e.g. cement, steel, etc.),
    b. Fossil fuels for energy.

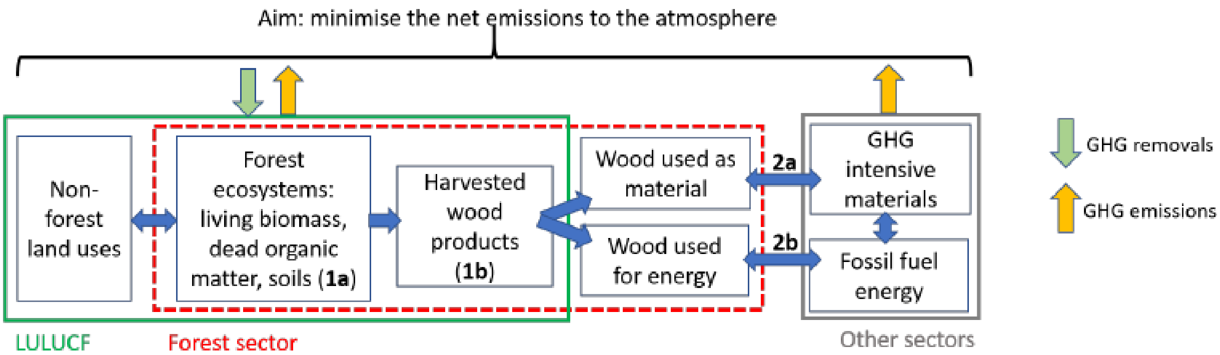


Figure 7 ***Role of bioeconomy in climate change mitigation increasing carbon stocks (1a and 1b) and substitution effects (2a and 2b). Using a forest and its harvested wood products as an example.***

Trade-offs and synergies exist among these possible contributions. The first trade-off occurs between increasing the carbon stocks of pools (1a) and making more biomass available for the other options (1b). In the short term, more harvest means a reduced net carbon sink. Within the other options, a synergy can occur between 1b and 2a, i.e. HWPs can store carbon over the long term and at the same time they can substitute functionally equivalent GHG-intensive materials. While trade-offs occur between 1b and 2b, i.e. the same biomass resource cannot be used at the same time for both material and energy application as shown in Figure 7. Even though biomass used for material application can later also be used for energy application at its end of life (see section 3.2 on cascading use of biomass).

A way to increase the net carbon stored in HWPs is to change how the harvested wood, industrial wood residues and secondary wood are used for different commodities. A shift from energy to materials and to wood products with a higher service life, e.g. from paper to construction timber, would slow down the release of carbon and help conserve or enhance the growth of the HWP pool, while maintaining a stable harvest over time.

Changes in carbon stocks are explicitly accounted for in the LULUCF sector, whereas the substitution effects are implicitly reflected in GHG emissions of other sectors. In line with internationally agreed rules (IPCC), the harvesting of biomass leads to direct emissions of carbon to the atmosphere (i.e. instantaneous oxidation), unless it can be shown that the biomass enters another carbon pool, such as dead wood, litter or soil, or is used to produce HWPs. In this way, biomass harvested for its use as energy is fully accounted for and reported as instantaneous GHG emissions under LULUCF. To avoid double counting, these emissions are zero-rated in the energy sector accounts.

3.1 Substitution effects

To assess the specific effect of using biomass to substitute energy or materials, life cycle assessment is applied. LCA provides an assessment of the potential environmental impact of a product or service throughout its entire life cycle by quantifying all inputs and outputs of material and energy flows and assessing how these flows affect the environment.

To evaluate the GHG emission savings that could be achieved by substitution, the life cycle GHG emissions associated with bioenergy or biobased products need to be calculated. This needs to be compared to a defined reference (benchmark) product which requires knowledge on the GHG emissions of this reference product. This reference product should be functionally equivalent.

Although all life cycle impact assessment methods are based on the ISO 14040/14044 standards, there is still a large degree of flexibility in terms of methodological choices in carrying out the assessments. The results of assessments differ considerably when applying different assessment methodologies. As a result, it is not possible to compare studies relying on different methodologies or studies conducted independently (Müller-Langer, F. et al., 2014). This also limits the applicability of defining benchmark values as results from one assessment framework cannot be taken as benchmarks for an assessment that is based on a different methodology. This means that the GHG emissions of the benchmark need to be determined following the same methodology to be able to make proper GHG emissions savings estimation.

For bioenergy and biofuels the revised Renewable Energy Directive (RED II) (European Commission-RED, 2018), provides a specific methodology for the calculation of GHG impact of bioenergy and biofuels, as well as default values for several production pathways. Fossil fuel comparators are defined for electricity, heat and biofuels to calculate GHG savings. RED II also defines GHG emissions saving criteria for bioenergy and biofuels.

For biobased products such a harmonised methodology or reference comparator values do not exist. There are some new initiatives in defining GHG emissions savings criteria for biobased products. In the recent Biobased Plastics Action Plan of the Transitie Team Kunststoffen, a minimum 30% GHG emission reduction (cradle to grave) was found to be suitable for biobased plastics. (Bergsma G., Broeren M., 2020). Looking at voluntary sustainability certification schemes currently applicable for biobased products, the RSB Advanced Products scheme (RSB, 2018) requires that, whenever certified final products are intended to replace fossil derived products. These certified final products must achieve at least 10% lower lifecycle GHG emissions calculated on a cradle-to grave basis relative to the lifecycle GHG emissions of a comparable fossil product. The operator must demonstrate that the systems being compared are equivalent; the system must be compared using the same functional unit and equivalent methodological considerations such as system boundary and allocation procedures. In ISCC Plus (ISCC, 2022), no specific GHG saving requirements exist for final products. Similarly, in Better Biomass (NEN, 2018), for the time being, no requirements are set for the net GHG emission reduction, due to the lack of (unambiguous) fossil reference situations. It is explained that validated fossil reference values are often not available and in many cases, it is not possible to determine unambiguously what the fossil reference is.

Detailed regulations and rules (e.g. ISO or EN standards or regulation defining the calculation framework in analogy with EU RED and the related communications for bioenergy and biofuels) for the calculation of GHG mitigation effects from biobased materials would help to harmonise the calculation procedure.

3.2 Cascading use of biomass

Cascading use is defined as the strategy to use "the biomass as long, often and efficiently as possible for materials and only to recover energy from them at the end of the product life cycle" (UBA, German Environmental Agency, 2017). Cascading use can provide substantial reduction in use of virgin resources by consecutively replacing virgin material needs with each application step and allow for highly resource-efficient use of biomass. (Höglmeier, K. et al., 2013), (Risse, M. et al., 2017), (Vis, M. et al., 2016)

Figure 8, this is illustrated for wood. Wood is ideally first used for construction as beams, then can be used to make particle board, paper, chemicals and energy as consecutive products, while at each stage maximizing closed loop recycling before moving down to lower quality applications. Cascading can be observed in current practice in the flow of materials between lumber, paper and energy sectors.

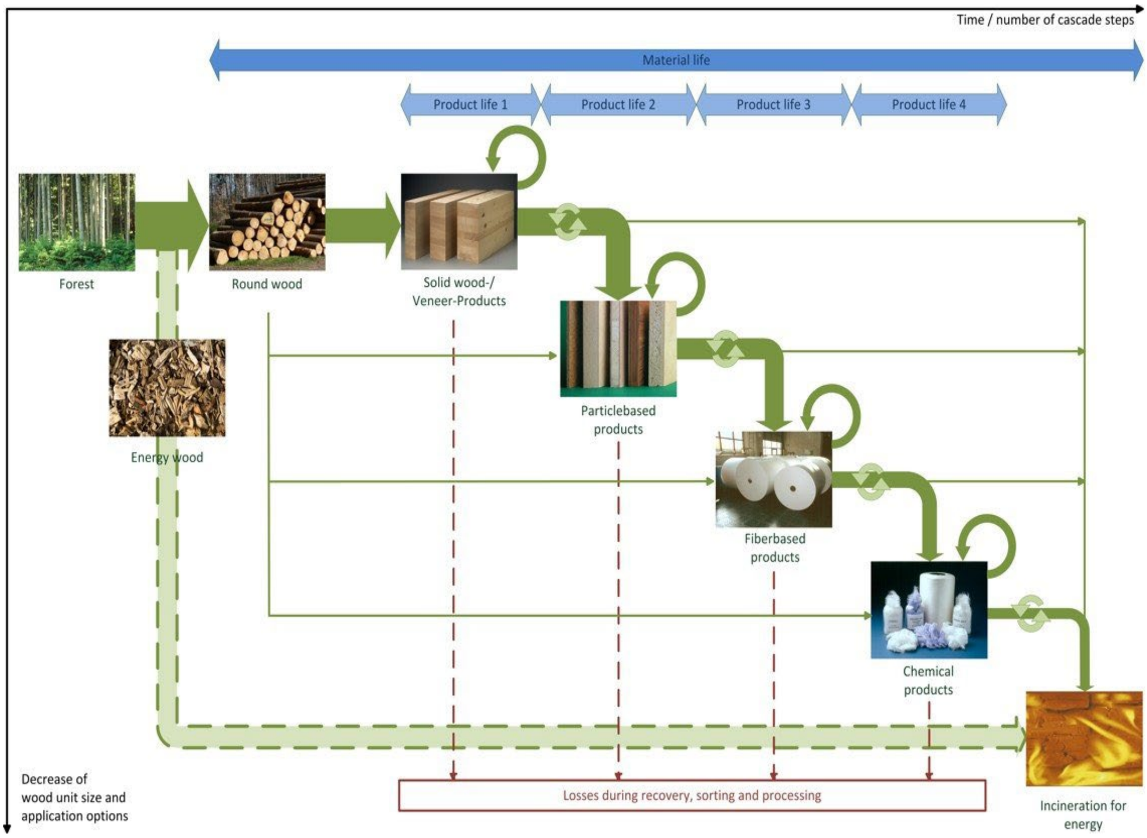


Figure 8 Cascading use of biomass with the example of wood (source: Hoglmeier, 2015) (Phys.org, 2017)

Currently biomass finds most use for energy, and thereby, is lost from the circular economy. This is also due to the existing renewable energy policy incentivizing use of biomass directly for energy (i.e. RED). Therefore, what is referred to as a "level playing field" is sought after to achieve more efficient allocation of biomass feedstock among material and energy applications and the establishment of more effective cascades. New policy frameworks need to encourage the cascading use of biomass, where biomass is used for materials and at the end of life (or final stage of the cascade) is released as much as possible for energy use. (Dammer, L., et al., 2016)

The Social and Economic Council in the Netherlands (Sociaal-Economische Raad, SER) notes that the use of biomass as feedstock in chemicals and materials is a necessary development for the creation of a carbon-neutral, circular economy and is also essential for maintaining the Dutch competitive position. (SER, 2020) They advise to focus on phasing in biobased chemicals and materials. The pace of development is limited by the speed at which new or existing applications can be scaled up and the availability of sustainable biomass. If circular principles are applied, the demand for virgin biomass will reduce if the market incentives are aimed at high-value rather than low-value utilisation. Policies are needed to accelerate the transition.

3.3 Carbon storage products according to the Regulation (EU) 2018/841

According to the report of 'Amending Regulations (EU) 2018/841 (European Parliament, 2021), several modifications related to the increase of biobased products and the contribution of the biobased economy to support the European goal of climate neutrality have been reviewed and adopted by the EU Parliement to negotiate positions during the trilogues meetings[15]. Table 6 shows the most relevant points regarding sustainable carbon storage in products. The final version of the revised text may be ready by the end of 2022 and publish in 2023, which is out of the temporary scope of this project.

Table 6 Points related to the creation of the new carbon storage products pool.

	Amendments related to the new categories of sustainable carbon storage products
Amendment-63, Proposal for a regulation Art.1 – Para.1 – point 7 – point b Regulation (EU) 2018/841 Article 9 – para 2	The Commission shall adopt delegated acts in accordance with Article 16 in order to amend paragraph 1 of this Article and Annex V by **adding new categories of harvested wood products that have a carbon sequestration effect, provided that methodologies for new categories are science-based, transparent, verifiable, avoid double counting, and are based on IPCC Guidelines** as adopted by the Conference of the Parties to the UNFCCC or the Conference of the Parties serving as the Meeting of the Parties to the Paris Agreement, and ensuring environmental integrity.
Amendment 28 Proposal for a regulation Recital 10	In order to enhance greenhouse gas removals, individual farmers, land and forest owners or forest managers should be encouraged to store more carbon on their land and their forests…. Such **incentives should also enhance climate mitigation and overall emission reduction across sectors in the bio-economy, including through the use of durable harvested wood products. Sustainably sourced long-lived harvested wood and biobased carbon storage products** can contribute to the circular bioeconomy by acting as substitutes for fossil-based options, but the potential for carbon storage in those products is determined by the lifespan of those products. The benefit of using wood to replace competing energies or materials with higher carbon footprints is also dependent on harvesting methods, transport and processing. Hence, **new categories of carbon storage products** may be introduced only if they are long-lived, have a net-positive carbon sequestration effect based on a life-cycle assessment, including the impact on land use and land use change associated with increased harvesting, and provided that the available data are science-based, transparent and verifiable.
Amendment 32 Proposal for a regulation Recital 10 d (new)	The potential for carbon storage in wood products is determined by the lifespan of those products, which can range from a few days for a leaflet, to decades or even hundreds of years for a wooden building. Although a **wood product does represent a carbon stock, the actual benefit of harvesting a tree depends on the lifespan of the product produced, which must be compared to that of the wood in the ecosystem if that tree had not been cut down.**
Amendment 3 Proposal for a regulation Recital 4 a (new)	The **substitution effect achieved through the use of agricultural and forestry raw materials**, especially wood and wood-based products, instead of fossil-fuel raw materials, **represents the climate protection performance of the sector, and is, as such, recognised and credited to the land use, land use change and forestry sector.**
Amendment 5 Proposal for a regulation Recital 5	In order to contribute to the increased ambition to reduce greenhouse gas net emissions from at least 40 % to at least 55 % below 1990 levels(…). The target for 2030 should be in line with sustainable forest management which allows for the adaptation of forests to climate change in the long term, **promotion of high substitution effects through the bioeconomy, an increase in sinks and the creation of carbon storage in products (…).**
Amendment 6 Proposal for a regulation Recital 5 a (new)	Taking into account the fact that the capacity of agricultural and forest ecosystems to sequester carbon depends on the sustainable management of land, forests and agroforestry, (…) as **sustainable management enhances resilience to climate change, sustainable management of forests is one of the tools to ensure that their capacity to absorb CO_2 is increased. Those positive effects can be enhanced by harnessing the carbon sink potential of forest stands. In addition, the use of long-lived timber products can ensure emissions are deferred.**
Amendment 15 Proposal for a regulation Recital 10	In order to enhance greenhouse gas removals, individual farmers or forest managers need a direct incentive to store more carbon on their land and their forests (…). New business models based on carbon farming incentives and on the certification of carbon removals need to be increasingly deployed in the period until 2030 and beyond.(…). Public funding under the Common Agricultural Policy (CAP) and other Union programs, such as the LIFE programme, the Cohesion Fund, the Horizon Europe programme, (…). Accounting should be in line with Article 6 of the Paris Agreement and outcomes of the 2021 Glasgow Summit to avoid double counting and enhance the development of robust and harmonized global accounting of carbon removals.(…). Such incentives and business models will enhance climate mitigation in a circular and sustainable bio-economy, including through the use of durable harvested wood products and by replacing fossil fuel-based raw materials in full respect of ecological principles fostering biodiversity and the circular economy. **A new category of carbon storage products, should be introduced in addition to harvested wood products, including relevant biobased products and innovative products, also made from by-products and residues, where there is a scientifically proven, genuine and verifiable carbon sequestration effect,**(…). **The Commission should also assess the substitution potential of carbon storage products.**

[15] A formal trilogue meeting, commonly known as a trilogue, is a type of meeting used in the European Union (EU) legislative process. Negotiations within three parties: European Commission, the Council of the European Union and the European Parliament.

	Amendments related to the new categories of sustainable carbon storage products
Amendment 41 Proposal for a regulation Art.1 – para.1 – point 7 – point b Regulation (EU) 2018/841 Article 9 – para. 2	The sustainable use of biomass and the increased demand for renewable products makes sustainable forest management indispensable. (…) The Commission shall adopt delegated acts by ... [3 months after the date of entry into force of this amending Regulation] in accordance with Article 16 in order to amend paragraph 1 of this Article and Annex V by **adding a new category of carbon storage products, including relevant biobased products that have a scientifically proven, genuine, verifiable carbon sequestration effect with accurate calculation methods to ensure credibility and to prevent fraud, and by introducing a holistic life-cycle assessment of those products,** including the potential of side streams and residues, and the inclusion of bioenergy carbon capture, storage and utilisation technologies in carbon storage products based on scientific evidence and on IPCC Guidelines as adopted by the Conference of the Parties to the UNFCCC (…).
Amendment 42 Proposal for a regulation Art. 1 – para.1 – point 7 – point b Regulation (EU) 2018/841 Art. 9 – para. 2 a (new)	The Commission shall furthermore **calculate the substitution effect of carbon storage products using scientific evidence. When IPCC Guidelines** are available, they shall also be taken into account.

Activities and initiatives involving the development and agreement on the methodologies for carbon accounting during biomass growth and during the life span of the biobased products at European level are in progress. Such the addition of the **'Carbon Storage Product'** pool (new amend Art.9 LULUCF to be ready between 2025-2027) which will include agricultural biomass and crop-based products and other relevant long-lived biobased products.

An important recommendation from WUR is not to attempt to (re)invent a new accounting methodology but to understand the existing IPCC Guidelines, LULUCF methodologies and LCA standards at global and EU level.

4 Examples of forestry and agricultural biomass chains to biobased products.

In this section, we provide two examples to illustrate how the GHG balances of different linear biobased supply chains are estimated at the product accounting level and how this relates to the national level inventory reporting. Three different frameworks (NACE[16], UNFCCC, the Dutch Climate Agreement) are used in the examples and the allocation of GHG emissions or removals to the different sectors or categories set by the framework are shown. The benefits or burdens associated with the production of the biobased products, depends on whether the production steps help a sector to meet their GHG targets under the Paris agreement (i.e. through lowering their GHG balances). The examples also show where there are "grey areas" or parts of the production chain where it is not clear to which sector the GHGs should be allocated and how GHG credits in turn can be transferred or related to the production level producers. In both examples, we focus only on the foreground part (the main production part) of the life cycle production system.

The allocation of the GHG gases according to the sectors of the different frameworks is the following:

- Sectors according to NACE: A. Agriculture, Forestry and Fishing, B. Mining and Quarrying C. Manufacturing, D. Electricity, Gas, Steam and Air Conditioning Supply, E. Water Supply; Sewerage, Waste Management and Remediation Activities, F . Construction, G. Wholesale and Retail Trade.
- Sectors according to UNFCCC: CRF1. Energy (fuel combustion, industry, public electricity and heat production, transport), CRF2. Industrial processes and product use (product manufacture and use emissions), CRF3. Agriculture, CRF4. LULUCF, CRF5. Waste.
- Sectors according to The Dutch Climate Agreement: C1. Built Environment, C2. Mobility, C3. Agriculture and land use, C5. Electricity.

4.1 Example 1. Carbon accounting for forestry and wood-based products

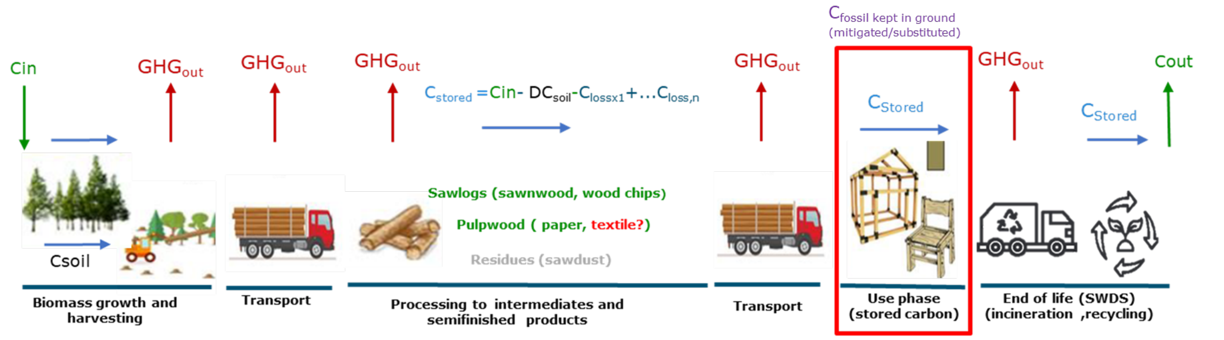
The life cycle of a wood-based products is illustrated in Figure 9. Due to the scope of this project, the analysis and discussion about the emission will focus on the initial stages biomass growth and harvesting, biomass processing and biobased product use.

Forest sequesters CO_2 and captures it in the biomass (trees) and the soil. Depending on the species of tree there are different rotation times and different application for the roundwood (approx. 80 years for trees that provide structural timber) (Ramage M.H. et al., 2017). When harvested trees are processed into wood products (e.g., wooden houses) an additional storage of carbon outside the forest is created. (Grassi, G. et al., 2021).

In the case of mature well managed forest no land use change occurs LULUCF (CRF4) as "forest remaining forest" and this is taken as an equilibrium state with high timber stocks, more carbon can be stored in the forest and product pool. The carbon in the HWP pool, just like the carbon in the forest, is part of the natural carbon cycle and delays the emission of carbon. Of course, in case of afforestation and deforestation, the impacts are positive and negative respectively and land use change must be taken into accountant (CRF4). The direct N_2O emissions from nitrogen inputs to forest soils must be reported under LULUCF in CRF4.

[16] NACE is the acronym used to designate the various statistical classifications of economic activities developed since 1970 in the European Union (EU). NACE provides the framework for collecting and presenting a large range of statistical data according to economic activity.

Industrial roundwood is the material inflow to the harvested wood-based products but the amount of harvested material does not necessary match with the production amounts of HWP because some biomass is lost during the harvesting, transport, and processing. These loses are considered as instantaneous oxidation unless it can be proven that the biomass enters another carbon pool such as dead wood, litter or soil. Only part of the harvested roundwood is used to produce wood-based products (sawnwood, wood base panels and paper and paperboard).



Framework	Biomass growth		Biomass Processing		Biobased product use	Biobased product end of life	Circularity secondary biomass
NACE	A.Agriculture, Forestry & Fishing	H.Transportation and storage	C. Manufacturing	H.Transportation and storage	F. Construction G. Retail (packing)	D. Energy E. Waste	Recycling
UNFCCC	CRF4. LULUCF [1] CRF1. Energy [2]	CRF1.Energy	CRF2.Industrial processes and product use	CRF1. Energy	CRF4. LULUCF (HWP in use)[3]	CRF4. LULUCF (HWP)	LULUCF (HWP)
Dutch Climate Agreement	C4. Agriculture and Land Use	C2. Mobility	C3. Industry	C2.Mobility	C3.Industry	C4. Agriculture and Land Use. C5. Electricity	

1. Soil carbon pool increases. For mature forests dLUC =0 (Land use remaining Land use balance–only machinery emissions taken into account)
2. Emissions from harvesting machinery
3. Harvested wood products (HWP) only Industrial roundwood. Until now few semi-finished wood products commodities (sawnwood, wood-based panels and paper and paperboard).

Figure 9 Example of wood-based product: GHG balances of a product identifying national inventory accounting. Graphic adapted from Welfele et al 2020.

The biomass processing is very energy intensive step because wood needs to be dried, cut and planned. The wood is also treated using chemical additives against biodegradation and to increase durability, the GHG emitted in this step are accounted in the UNFCCC as CRF2 Industrial processes and in the Dutch Climate Agreement they are assigned to C3. Industry.

During the use phase, the carbon storage is accounted in the Harvested Wood Products pool (CRF4-HWP) according to the UNFCCC. For the Dutch Climate Agreement, it may be more associated to the substitution effect of the GHG -intensive materials like of steel and concrete (C3. Industry) but this not yet clear in the Climate Agreement and the IPCC does not provide methods to assess substitution benefits, because they are implicitly included in the non-LULUCF sectors (e.g reduced emissions from cement or steel production).

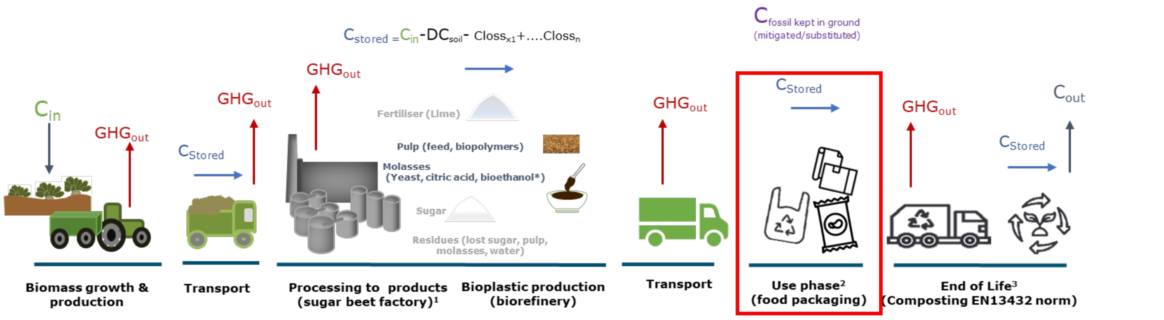
For the UNFCCC accounting approach, it is important to have verifiable and transparent data on the amount of semi-finished products and half-life of the different wooden products (number of years it takes to lose on half of the material in the pool). Following the UNFCCC accounting line, the potential of forest-based materials to contribute to the climate targets and decrease the GHG emissions could be achieve in different ways:

- Reduce harvesting to increase the net forest sink, appears to be a simple option, however this option could also have negative impacts if forest sink saturation is reached and the socio-economic impact in forestry biobased economy due to a limited production of wood.
- Increase the amount of HWP, this would increase wood availability for material substitution and more carbon will be stored in the HWP pool. Nevertheless, this could carbon sink in the forest pool.
- Increase the carbon storage in the HWP is to switch the production to harvested wood with a higher service life (e.g. produce more construction timber instead of paper). This will would slow down the outflow of carbon from the HWP pool. This option is in alignment with the recent amendments to the Regulation (EU) 2018/841 and what is mentioned in the Climate Agreement.

In the use phase, it is important to search for available and transparent data on the half-life of the different wooden products (number of years it takes to lose on half of the material in the pool) of wood products. The transport emissions for the wood-based products, these are attributed to the Energy sector (UNFCCC) while the Climate agreement they are may be assigned to mobility sector.

4.2 Example 2. Carbon accounting for agro-based product: from sugar beet to biobased packing.

In this example we also focus on the foreground part (the main production part) of the life cycle production system. It is broken into six major production steps. At the beginning of the biobased chain is the growth and production of sugar beet. (See Figure 10)



Framework	Biomass growth		Biomass Processing		Biobased product use	Biobased product end of life	Circular [4] Secondary biomass
NACE	A. Agriculture, Forestry & Fishing	H.Transportation and storage	C. Manufacturing	H. Transportation and storage	C.Manufacturing G. Retail (packging)	D. Energy, E. Waste	Residues Agriculture
UNFCCC	CRF3.Agriculture CRF4. LULUCF*	CRF1.Energy	CRF2. Industrial processes and product use. (ETS)[1]	CRF1. Energy	CRF3. Agriculture	CRF 5.Waste	CRF5. Waste CRF2. Industrial processes and product use. CRF3. Agriculture
Dutch Climate Agreement	C4.Agriculture and Land Use	C2.Mobility	C3.Industry	C2. Mobility	C4. Agriculture and Land Use	C5.Electricity (heat)	

1. Sugar beet factories are energy intensive industries and are part of the Emission Trading Scheme (ETS)

2. Use phase products with relevant TRL levels (8+) are packaging for food assumed to have a short life span of <1 year (Total Corbion, 2020; van den Oever, 2017; Ghomi et al 2021)

3. According to EN standards composting should take approx. 3 months, but studies indicate a range of different time spans from 2 weeks to 1+ year if standard composting not carried out. Mechanical and Chemical recycling are possible, however are not authorised for recirculation within the food system only PET (Total Corbion, 2020; van den Oever, 2017;Ghomi et al 2021)

4. While promoting the development of biobased products also important to accommodate the preferential end of life option of each product in the waste processing system

*If dLUC not happening Land use remaining Land use Soil emissions in Agri Annual biogenic carbon assumed to balance – only machinery emissions considered

Figure 10 Example of agro-based product: GHG balances product identifying national inventory accounting. Graphic adapted from Welfele et al 2020.

Sugar beet will normally be grown as part of a rotation and as such no land use change will be required to produce it. Therefore, it will appear in the LULUCF (CRF3) as "cropland remaining cropland" in relation to estimating the carbon flows or CO_2, either removals or releases. In addition to the LULUCF allocation of carbon, the other GHG emissions (e.g. N2O emissions from soils), will be attributed to Agriculture (C4). Both the LULUCF and the Agricultural accounting categories are part of the Effort Sharing Agreement. It is also important to note here the EU's promotion and the direction they are taking towards carbon farming (European Commision-CF, 2021), as this will become a very important accounting mechanism when we talk about sourcing land-based biomass from the agricultural system. It will determine what are valid accounting rules for storing carbon in agricultural soils and products and such how biobased products may need to be monitored (e.g. frequency of soil samples, satellite images, farm mass balances), reported and validated (e.g. comparative baselines, benchmarks)

Additionally, transport also falls under the ESA agreement. However, the emissions associated with transporting the biomass and biobased product, under the UNFCC accounting are assigned nationally to the Energy sector and under the Dutch Climate Agreement they are assigned to the Mobility sector. Whereas, at the production chain level, the life cycle method allocated these emissions to the biobased plastic product. What is important to note her is that Transport is an emitting sector (i.e. releasing GHGs) and therefore, will need to mitigate its emissions through absolute reductions or through off-setting or insetting[17] This is where there is a potential link back to carbon farming and carbon certification associated with voluntary carbon markets. (European Court of Auditors, 2014)

In relation to the conversion of the sugar beet into sugar products or additional biobased products, such as bioplastics (e.g. PLA, poly lactic acid), sugar beet factories due to their energy intensity are part of the Emissions Trading scheme (ETS) and fall under Industry in both the UNFCC national accounting scheme (CRF2) and the Dutch Climate Agreement (C3). Producing the sugar and biobased products will result in emissions, hence this processing step acts as a source of GHG release. This sector will have to pursue absolute reductions due to decreasing credits allowed. However, they may also try to reduce its emissions in relation to in-setting in its supply chain or apply for offsets as part of the ETS (European Commission - Press Corner, 2021). The ETS and the voluntary carbon markets are ideally two separate things. But there is potential for grey areas in relation to insetting along such production chains.

Plastic biobased products are likely to be determined as short-lived carbon products, meaning that some biogenic carbon is stored for a short period (several months to 2 years) (Oever van den M. et. al., 2017). What is important to note here is that under both national accounting schemes (UNFCCC and the Dutch Climate Agreement) the use phase is not taken into account. Such details can be however, considered at the production chain level accounting.

Furthermore, in a linear chain the emissions associated with the disposal of such plastic products also become unclear. In our example we have assumed it could end up in the waste category of the UNFCC (CR5) or in an effort to integrate it within the Dutch Climate Agreement we allocated it into the electricity category (C5), if we assume the bioplastic is used for energy recovery. This lack of clarity is very important to recognize, as which national accounting category does such a product belong to and where are the associated GHG releases allocated? This will gain increasing importance, with the aim of going towards a circularly economy.

[17] "Carbon offsetting is a mechanism whereby individuals or organisations compensate for their own GHG emissions or for a part of them by paying for an equivalent GHG saving made elsewhere in the world, e.g. emissions savings made through wind farms that replace coal-fired power plants." (EU, 2014). Not in a company's own value chain. Insetting projects are interventions along a company's value chain that are designed to generate GHG emissions reductions and carbon storage, and at the same time create positive impacts for communities, landscapes and ecosystems. https://www.insettingplatform.com/insetting-explained/

5 Conclusions and recommendations

Bioeconomy has the potential to contribute to tackling climate change through

1. Increasing carbon stocks (creating a 'net sink' for CO_2):
   a. In the forest or agricultural land (sequestration);
   b. In the HWP or Carbon Storage Products pool (storage);
2. Mitigation by substitution (preventing or reducing the release of GHGs), i.e. using wood to replace:
   a. Functionally equivalent materials (e.g. cement, steel, etc.),
   b. Fossil fuels for energy.

- Sustainable practices in forest management are relevant to address problems regarding sink saturation in the forest and to assure the transferring the carbon to the HWP pool while also having socio-economic benefits.

- There is room for improvement of the HWP carbon pool reporting and accounting. Currently in the EU only France uses national estimates for half-lives, the other member states apply the default half-life times of 2 years for paper, 25 years for wood panels and 35 years for sawnwood. As a result, the effects of biomass policies and innovations in the wood sector are not reflected in the national GHG inventories and GHG accounting under the Paris Agreement. To be able to include these effects new data on the HWP pool, like actual half-life times and how innovations may affect half-life times of wood products is needed. Factors like technological improvement in the wood industry, the new innovative wood products with longer service life, the utilization of low-quality and small diameter logs, higher wood products processing efficiency and increase of the recycling rate need to be considered because they could potentially expand the size of the HWP carbon pool.

- Additionally, this will require collaboration and information exchange between European countries. The EU-LULUCF regulation requires that Member States report carbon stock changes in exported HWP using the half live times of the importing country. This will require not only improved half-lives from domestic use, but also to get such information from other countries (EU, but also external). For example, for HWP from domestically harvested wood that is exported to Germany, the Netherlands needs to use the German half-life times used for that product, and for a similar product that is exported to Spain it needs to use the Spanish half-life times used for that product category. In principle, the typical ways of using wood in a country would be more important, but likely there will be interactions. If for instance Germany would import mainly cross-laminated timber to be used in buildings from the Netherlands and wood-pulp or paper from France, then the use very much determines the results.

- It is clear, from a policy and governance point of view, that biobased products derived from forest materials already have very strong accounting protocols that can be followed at the national level. These will more than likely form the foundations for future developments and advancements when it comes to the "Carbon Storage product pool" (new amend Art.9 LULUCF to be ready between 2025-2027). Which proposes to include carbon removal (via sequestration and storage of carbon in soils and biomass) and introduce more explicit pathways for biobased products (forest-based and agro-based) like construction materials, fibres and polymers. However, currently there is no carbon pool linking the agricultural biomass to crop-based products.

- For biobased products sourced from agricultural land, the developments under way at EU level for supporting carbon farming and carbon certificates, as outlined in this report, will play an important role in establishing the appropriate accounting frameworks due to the need for monitoring, reporting and validation of the carbon certificates. At product level, there is currently no consensus across these different standards and guidelines on how to handle biogenic carbon emissions and removals from products, and any resulting storage of biogenic carbon in biobased products. There are many opportunities to explore carbon farming options at both a national and EU level, particularly if the direction taken to finance these carbon credits will be done through the Common Agricultural Policy strategic plans.

- It is important to understand and recognize the value in current existing accounting methodologies as outlined in this report. However, many of the existing tools and frameworks are lacking important features (as they have been developed for very specific goals) which could enable more robust and reliable means to account for biogenic carbon sequestration and storage in biogenic products. Such accounting considerations will be crucial to guide the material transition in the right direction towards climate neutrality. There is also a lack of consistency between the different scales, making it difficult to ensure that the right flows can be accounted for towards a countries or sectors emissions targets. Once the limitations of these approaches have been identified and discussed, new opportunities can be created to make adaptations, improvements and advancements that will enable a more harmonised and complementary use of the different approaches. In this way, the required multi-level approach can be established to ensure that any double accounting discrepancies or absolute increases in GHGs can be avoided when transitioning to a circular and biobased economy.

Recommendations:

- To start assessing how to improve the information regarding the domestic half-lives time of different products included in HWP carbon pool at national level. This can be done by initiating research projects that look for more realistic and accurate data on the amount and lifespan of biobased products. Gathering this information may be challenging but it is relevant to support further policy development.

- To encourage the cascading use of biomass, where biomass is used for materials in new policy frameworks. Cascading use of biomass is currently not supported enough and there is a need to encompass all stages of production, including the design phase to ensure the potential for reuse as another form, with the last phase or end of life (or final stage of the cascade) being used for energy production. This is a necessary development for the creation of a carbon-neutral, circular economy and is also essential for maintaining the Dutch competitive position.

- To try to assess consequences of the recent proposal of the European Commission for a regulation establishing the framework for the certification of carbon removals. It is important not to overlook aspects such quantification of baselines, how to do the monitoring, reporting and validation of emission and removals and the establishment of data for long term carbon storage in products according to product's lifetime to ensure genuine carbon reductions related to the use of biobased products. In the next months, Member States need to determine their position and negotiate the position of the EU council for upcoming negotiations between Commission, EU Parliament and Council.

- To follow the evolution of detailed regulations and rules (e.g. ISO or EN standards or regulation defining the calculation framework in analogy with EU RED and the related communications for bioenergy and biofuels) for the calculation of GHG mitigation effects from biobased materials which would help to harmonise the calculation procedure. There is an ongoing initiative at the European level: the European Committee for Standardization (CEN) Technical Committee TC411, working group WG4 "Sustainability criteria, life cycle analysis and related issues" is working on creating a new additional European standard concerning comparative LCAs for biobased products with their fossil-based counterparts.

6 Bibliography

Bergsma G., Broeren M. (2020). Transitieteam Kunststoffen. Actieplan Biobased Kunststoffen. .

British Standards Institution (BSI). (2011). *PAS 2050. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.*

CO_2 Value Europe. (2022, December). *The European Association dedicated to the conversion of CO2 into valuable products*. Retrieved from https://co2value.eu/what-is-ccu/

European Parliament. (2020). *Commision Implementing Regulation (EU) 2020/1208 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and of the Council.* Retrieved from https://eur-lex.europa.eu/eli/reg_impl/2020/1208/oj

European Parliament. (2021, June 08). *Report on the proposal for a regulation of the European Parliament and of the Council Amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the co.* Retrieved from https://www.europarl.europa.eu/doceo/document/A-9-2022-0161_EN.html

Goverment of the Netherlands. (2019, 06 28). National Climate Agreement of the Netherlands. The Hague, Netherlands. Retrieved from https://www.government.nl/topics/climate-change/climate-policy

AGRI, D. V.-D. (2022).

Arets, E.J.M.M., et al. (2022). *Greenhouse gas reporting of the LULUCF sector in the Netherlands. Methodological background, update 2022WOt Technical report 217. Greenhouse gas reporting of the LULUCF sector in the Netherlands. Methodological background, update 2022. .* Wageningen .

Breton C., B. P.-S. (2018). Assessing the climate change impacts of biogenic carbon in buildings: A critical review of two main dynamic approaches,. *Sustainability , 10*(6).

Cherubini, F., et al. (2011). CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. . *GCB Bioenergy, 3*(5), 413–426.

Dammer, L., et al. (2016). *Cascading use of wood products.* World Wide Fund for Nature.

Di Virgilio N.-DG AGRI. (2022). "The role of the CAP in promoting carbon farming". Presentation at the "Second EUSO Stakeholders Forum". Retrieved from https://esdac.jrc.ec.europa.eu/euso/second-euso-stakeholders-forum

Directorate-General for Internal Market, I. E. (n.d.). Bio-based products. Retrieved from https://single-market-economy.ec.europa.eu/sectors/biotechnology/bio-based-products_en

Encyclopedia Britannica. (2022, Nov. 14). *The Information Architects of Encyclopaedia. "carbon sequestration"*. Retrieved from https://www.britannica.com/technology/carbon-sequestration.

EPA. (2016). Retrieved from https://www.epa.gov/sites/default/files/2016-03/documents/life-cycle-ghg-accounting-versus-ghg-emission-inventories10-28-10.pdf

EPA. (2022). *United States Enviromental Protection Agency*. Retrieved from https://www.epa.gov/ghgemissions/overview-greenhouse-gases: https://www.epa.gov/ghgemissions/overview-greenhouse-gases

European Comission. (2021, July 14). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550&from=EN

European comission-CFI. (2021, April 27). Climate Action. Retrieved from https://climate.ec.europa.eu/news-your-voice/news/commission-sets-carbon-farming-initiative-motion-2021-04-27_en

European Commision . (2022). *Joint Research Center-Forest* . Retrieved from https://forest.jrc.ec.europa.eu/en/activities/lulucf/

European commision glossary. (2018). Retrieved from https://knowledge4policy.ec.europa.eu/glossary-item/carbon-pool_en.

European Commision. (2018). *PEF Product Environmental Footprint Category Rules Guidance, Version 6.3.*

European Commision-CEE. (2022). *Energy and the Green Deal.A clean energy transition*. Retrieved from Directorate-General for Communication: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/energy-and-green-deal_en#in-the-spotlight

European Commision-CF. (2021, December 15). *Directorate-General for Climate Action*. Retrieved from Sustainable carbon cycles: https://ec.europa.eu/clima/eu-action/forests-and-agriculture/sustainable-carbon-cycles_en
European Commision-F2F. (2020). *Farm to fork strategy. For a fair, healthy and environmentally-friendly food system.* Retrieved from Directorate-General for Health and Food Safety: https://food.ec.europa.eu/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf
European commision-SCC. (2022). *Sustainable carbon cycles*. Retrieved from EU Directorate-General for Climate Action: https://climate.ec.europa.eu/eu-action/sustainable-carbon-cycles_en
European Commission - Press Corner. (2021, July 14). Questions and Answers - Emissions Trading – Putting a Price on carbon . Brussels. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3542
European Commission - Press release. (2022, November 20). European Green Deal: Commission proposes certification of carbon removals to help reach net zero emissions. Brussels. Retrieved from file:///C:/Users/garci081/Downloads/European_Green_Deal__Commission_proposes_certification_of_carbon_removals_to_help_reach_net_zero_emissions.pdf
European Commission. (2018, June 18). *Regulation (EU) 2018/841 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.* Retrieved from Publications Office.
European Commission- JRC. (2010). *Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook – General Guide for Life Cycle.* Luxembourg.: Office of the European Union.
European Commission PEF. (2013). *PEF Guide, Annex to Commission Recommendation 2013/179/EU on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. .*
European Commission-BDS. (2022). *Strategy*. Retrieved from Biodiversity Strategy 2030: https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
European Commission-CAP. (2021, December 2). *The new common agricultural policy*. Retrieved from Directorate-General for Agriculture and Rural Development: https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/new-cap-2023-27_en
European Commission-CEAP. (2022). Retrieved from Directorate-General for Environment: https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
European Commission-ED. (2022, March 30). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. On making sustainable products the norm.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090
European Commission-JRC. (2021). *Brief on the role of the forest-based bioeconomy in mitigating climate change through carbon storage and material substitution. .* Retrieved from European Commission's Knowledge Centre for Bioeconomy.
European Commission-RED. (2018, December 11). *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG
European Commission-RME. (2020, October). *Methane emissions. Reducing energy-related methane emissions will boost the clean energy transition in Europe.* Retrieved from Directorate-General for Energy: https://energy.ec.europa.eu/topics/oil-gas-and-coal/methane-emissions_en
European Commission-SS. (2021, November 17). Communication from the commision to the European Parlament, the Council and the committee of the regions. EU Soil Strategy for 2030 Reaping the benefits of healthy soils for people, food, nature and climate. Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52021DC0699
European Commission-ZPAP. (2021, May 12). Communication form the commission.Pathway to a Healthy Planet for All EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'. Brussels.
European Commisson- ACC. (2021, February 24). *EU Adaptation Strategy*. Retrieved from https://climate.ec.europa.eu/eu-action/adaptation-climate-change/eu-adaptation-strategy_en
European Council-GD. (2022). Retrieved from European Green Deal: https://www.consilium.europa.eu/en/policies/green-deal/

European Court of Auditors. (2014). *How do the EU institutions and bodies calculate, reduce and offset their greenhouse gas emissions? (pursuant to Article 287(4), second subparagraph, TFEU).* Luxembourg: Publications Office of the European Union.

European Parliamentary Research Service. (2022, February). New EU forest strategy for 2030. *PE 698.936* . Retrieved from https://www.europarl.europa.eu/RegData/etudes/ATAG/2022/698936/EPRS_ATA(2022)698936_EN.pdf

European Standard EN 16760. (2015). *EN 16760:2015 Biobased products – Life Cycle Assessment.*

European Standard EN-15804. (2019). *Sustainability of construction works—Environmental product declarations—Core rules for the product.*

FAO. (2021). *Food and Agricultural Organization of the United Nations*. Retrieved from FAOSTAT: https://www.fao.org/faostat/en/#data

Forlin V. DG CLIMA. (2022, October 26). "Carbon farming in the EU". Presentation at the "Second EUSO Stakeholders Forum". *DG Clima*. Retrieved from https://esdac.jrc.ec.europa.eu/public_path/public_path/EUSO-SHF-2022/EUSO%20Stakeholder%20Forum%20-%20Agenda%20-2022-10-24.pdf

Grassi, G. et al. (2021). *JRC124374. Brief on the role of the forest-based bioeconomy in mitigating climate change through carbon storage and material substitution.* European Commision.

Greenhouse Gas (GHG) Protocol. (2011). *Product Life Cycle Accounting and Reporting Standard.* World Resources Institute & World Business Council for Sustainable Development. Retrieved October 10, 2022, from https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

Hendriks, C. E. (2021). *LULUCF : Land Use, Land-Use Change and Forestry. WOt-special 3. Wettelijke Onderzoekstaken Natuur & Milieu, .* Wageningen . Retrieved from https://edepot.wur.nl/545713

Höglmeier, K. et al. (2013). Potentials for Cascading of Recovered Wood from Building Deconstruction: A Case Study for South-East Germany. *Resour. Conserv. Recycl., 78*, 81–91. doi:10.1016/j.resconrec.2013.07.004.

Hoxha, E., A. et al. (2020). Biogenic carbon in buildings: a critical overview of LCA methods. *Buildings and Cities, 1*(1), 504-524.

IPCC. (2005). *IPCC Special Report on Carbon Dioxide Capture and Storage.* New York. Retrieved from https://www.osti.gov/biblio/20740954

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use. IPCC National Greenhouse Gas Inventories Programme. .* Institute for Global Environmental Strategies (IGES), Kanagawa, Japan .

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Kanagawa, Japan: IPCC National Greenhouse Gas Inventories Programme. Published by the Institute for Global Environmental Strategies (IGES).

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme.* Kanagawa, Japan: Institute for Global Environmental Strategies (IGES).

IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories Chapter 3.2. Land Use Catergories.* Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_03_Ch3_Representation.pdf

IPCC. (2019, IPCC guidelines are mandatory, and the 2019 refinement may be used if justified.). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.Volume 4, Agriculture, Forestry and Other Land Use.* Switzerland: IPCC. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/index.html

IPCC. (2022). Retrieved from https://archive.ipcc.ch/organization/organization_history.shtml

IPCC,2021. (2021). *Summary for policy makers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC.* New York: Cambridge University Press. doi:10.1017/9781009157896.001

IPI. (2022). *International Platform for Insetting* . Retrieved from https://www.insettingplatform.com/insetting-explained/

IRENA. (2022). *NDCs and renewable energy targets in 2021: Are we on the right path to a climate-safe future?* Abu Dhabi: International Renewable Energy Agency,. Retrieved from file:///C:/Users/garci081/Downloads/IRENA_NDCs_RE_Targets_2022%20(1).pdf

ISCC. (2022). ISCC Plus System Document v3.2,. International Sustainability and Carbon Certification . Retrieved from https://www.iscc-system.org/

ISO. (2006). ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework; ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines. Retrieved from https://www.iso.org/standard/37456.html

ISO. (2017). *ISO 21930:2017, Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.*

ISO. (2018). *ISO 14067:2018 GHGes – Carbon Footprint of products – Requirements and guidelines for quantification.*

Iversen P., L. D. (2014). *Understanding Land Use in the UNFCCC.*

Levasseur, A., et al. (2010). Considering time in LCA: Dynamic LCA and its application to global warming impact assessments. *Environmental Science & Technology, 44*(8), 3169–3174.

McLaren D. P., e. a. (2019). Beyond "Net-Zero": A Case for Separate Targets for EmissionsReduction and Negative Emissions. *Frontiers in Climate, 1:4*. doi:10.3389/fclim.2019.00004

Minx J. C., e. a. (2018). Negative Emissions—Part 1: Research Landscape and Synthesis. *Environmental Research Letters* (6). doi:10.1088/1748-9326/aabf9b

Minx, J. e. (2017). Fast Growing Research on Negative Emissions. *Environmental Research Letters, 12* (3). Retrieved from https://doi.org/10.1088/1748-9326/aa5ee5*

Moosmann L., et al. (2019). *International Climate Negotiations - Issues at stake in view of the COP 25 UN Climate Change Conference in Madrid.* Study for Committee on the Environment, Public Health and Food Safety of the European Parliament, European Parliament, Luxembourg.

Müller-Langer, F. et al. (2014). Benchmarking biofuels—a comparison of technical, economic and environmental indicators. *Energ Sustain Soc., 4*(20). Retrieved from https://doi.org/10.1186/s13705-014-0020-x

Nabuurs, G. P. (2015). *A new role for forests and the forest sector in the EU post-2020 climate targets.* European Forest Institute. Retrieved from http://edepot.wur.nl/371799.

NEN. (2018). NCS 8080:2018-08.Better Biomass certification scheme. Retrieved from https://betterbiomass.nl/wp-content/uploads/2018/08/NCS-8080_2018-08-en-Better-Biomass-certification-scheme.pdf

Nicola di Virgilio, D. A. (n.d.). The role of the CAP in promoting carbon farming. Presentation at the "Second EUSO Stakeholders Forum".

O'Keeffe, S., et al. (2016). When considering no man is an island—assessing bioenergy systems in a regional and LCA context: a review. *The International Journal of Life Cycle Assessment, 21*(6), 885-902.

Oever van den M. et. al. (2017). *Bio-based and biodegradable plastics – Facts and Figures Focus on food packaging in the Netherlands. Report 1722.* Wageningen.

PCAF. (2020, November 18). *The Global GHG Accounting and Reporting Standard for the Financial Industry.* Retrieved from https://carbonaccountingfinancials.com/files/downloads/PCAF-Global-GHG-Standard.pdf

Phys.org. (2017, December 12). *Cascading Use of Wood to Ensure Sustainability Available.* Retrieved from https://phys.org/news/2017-12-cascading-wood-sustainability.html.

Ramage M.H. et al. (2017). *Renewable and Sustainable Energy Reviews. ISSN 1364-0321., 68*, 333-359.

Risse, M. et al. (2017). Resource Efficiency of Multifunctional Wood Cascade Chains Using LCA and Exergy Analysis, Exemplified by a Case Study for Germany. *Resour. Conserv. Recycl., 126*, 141–152.

RSB. (2018). Standard for Advanced Products. RSB-STD-02-001 (version 2.0). Retrieved from https://rsb.org/wp-content/uploads/2018/03/18-03-22_RSB-STD-02-001-v2.0-RSB-Standard-for-Bio-based-and-Advanced-Products_rev.pdf

Ruter S., et al. (2019). *IPCC Refinement to the 2006 IPCCC Guidelines for National Greenhouse Inventories-Vol 4. Agriculture, Forestry and other Lad Use.IPCC Chapter 12. Harvested Wood Products. In:.*

Sato, A. e. (2019). Assessing the contribution of harvested wood products under greenhouse gas estimation: accounting under the Paris Agreement and the potential for double-counting among the choice of approaches. . *Carbon Balance and Management* .

SER. (2020). *SER Biomass in the Balance. A Sustainability Framework for High-Value Use of Bio-Based Raw Materials; Social Economic Council. Advisory Report 20/07. .* Den Haag.

Thorsøe, M. (2022). EJP SOIL:ROAD4SCHEMES PROJECT. Presentation at the "Second EUSO Stakeholders Forum". Retrieved from https://esdac.jrc.ec.europa.eu/public_path/shared_folder/EUSO/second-SHF-presentations/OC/4_MartinThorsoe_Thors%C3%B8e%20EUSO%20seminar.pdf

UBA, German Environmental Agency. (2017). *Biomass Cascades. Increasing Resource Efficiency by Cascading Use of Biomass: from Theory to Practice.* Dessau-Roßlau. Retrieved from http://www.umweltbundesamt.de/publikationen

UNECE. (2022, July 30). Retrieved from United Nations Economic Commission for Europe: https://unece.org/forests/carbon-storage-harvested-wood-products-hwp

UNECE. (2022). *Forest. Carbon Storage in Harvested Wood Products (HWP).* Retrieved from https://unece.org/forests/carbon-storage-harvested-wood-products-hwp

UNFCCC. (2009). *Resource Guide Module 3. National Greenhouse Gas Inventories.* Retrieved from https://unfccc.int/resource/docs/publications/09_resource_guide3.pdf

UNFCCC. (2022). *United Nations Climate Change*. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

UNFCCC. (2022). *United Nations Climate Change* . Retrieved from https://unfccc.int/process-and-meetings/the-convention/status-of-ratification-of-the-convention

United Nations. (2021). *United Nations. Climate Action*. Retrieved from https://www.un.org/en/climatechange/paris-agreement

Ventura, A. (2022). Conceptual issue of the dynamic GWP indicator and solution. *Int J Life Cycle Assess.* Retrieved from https://doi.org/10.1007/s11367-022-02028-x

Vis, M. et al. (2016). *Study on the Optimised Cascading Use of Wood. No 394/PP/ENT/RCH/14/7689.* Luxembourg. Publications: Office of the European Union.

World Bank. (2020). *Reference Guide to Climate Change Framework Legislation.* Washington DC. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/34972/World-Bank-Reference-Guide-to-Climate-Change-Framework-Legislation.pdf?sequence=6

Zampori L. and Pant R. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method.* Luxembourg.: Publications Office of the European Union,.

To explore the potential of nature to improve the quality of life

Wageningen Food & Biobased Research
Bornse Weilanden 9
6708 WG Wageningen
The Netherlands
E info.wfbr@wur.nl
wur.nl/wfbr

Report 2388

The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR's Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.