Open-BIO

Opening bio-based markets via standards, labelling and procurement

Work package 3

Bio-based content and sustainability impacts

Deliverable N° 3.6

Bio-based sustainability schemes

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Summary

The project Open-Bio aims to open markets for bio-based products by standardisation, labelling and procurement. This report identifies and explores sustainability issues relevant for bio-based products. It investigates what lessons can be learned from biomass sustainability schemes for bioenergy and biofuels and what topics not currently covered in biomass sustainability schemes such as cascading use, ILUC, and carbon storage in products mean for bio-based products. The report forms a Deliverable under Work Package 3 "bio-based content and sustainability impacts" of the Open-Bio project, see http://www.bio-basedeconomy.eu/research/open-bio/. Table 1 provides an overview of sustainability assessment topics relevant for bio-based products and its current coverage in biomass certification schemes. The bio-based products are classified based on the type of biomass.

Table 1 Overview of relevant sustainability topics for bio-based products

Sustainability theme	Bio-based products			Bioenergy and biofuels	Covered in biomass certification schemes
Biomass type	Oil bearing	Sugar and starch	Lignocellulosic biomass		
Sustainable production • Environmental • Social • Economic	Y	Y	Y	Y	✓
GHG reduction	Y	Y	Y	Y	✓
Indirect land use change	Y	Y	N	Y	✗ a)
Carbon debt	N	N	Y	Y	✗
Carbon storage	Y	Y	Y	N	✗
Cascading of biomass	Y	Y	Y	Y	✗ b)
Bio-based carbon content	Y	Y	Y	Y	✓

Y= relevant; N= not relevant; ✓= covered in existing sustainability certification schemes; ×= not covered in existing sustainability schemes

a) RSB and Better Biomass offer the possibility to show that biomass is low ILUC impact.

b) Better Biomass (NTA8080-1:2015) has a reporting obligation on cascading use.

The sustainability of the production of biomass is not different whether the biomass is used for energy, fuels or bio-based products. It will strongly depend on the type of biomass, e.g. oil bearing, sugar and starch or lignocellulosic, and the way it is produced. Therefore, existing biomass sustainability certification schemes related to biomass for bioenergy and biofuels can be adjusted to certify the sustainable production of biomass for bio-based products as well. The Better Biomass, ISCC-PLUS and RSB schemes have already implemented such adjustments.

Greenhouse gas emission reduction is one of the main environmental benefits of bio-based products and should therefore be addressed properly. The Open-Bio project shows that the impact of bio-based products on climate change/CO_2 emission savings are regarded very important by NGOs and public procurers and regarded relevant by consumers as well.

Determination of **greenhouse gas emission savings** is more complex in case of bio-based products compared to biofuels and bioenergy, because the production processes of the bio-based product and the fossil benchmark are generally more complex. Moreover, there are a limited number of biofuels and bioenergy production pathways, while the range of possible bio-based products and their fossil benchmarks is large. Determining the greenhouse gas emission reduction and other direct environmental impacts requires the performance of a **Life Cycle Assessment (LCA)**. The question arises in how far these LCAs produce comparable results. Comparison and analysis of 23 LCAs of bio-based products show that the LCAs apply different scopes and methods regarding several critical issues. GHG emissions are calculated in all reviewed articles, but their impact is determined differently. For example, different LCIA methods are chosen, which influence how the impact of GHG emissions is regarded. Energy use is addressed by 18 articles, of which most quantify the impact of either the cumulative energy demand (CED) or the non-renewable energy use (NREU). In contrast to the direct calculation of GHG emissions, factors influencing these emissions are considered to a highly varying degree. Diverging energy use indicators are applied (e.g. considering all energy sources *vs.* only non-renewable energy), and ILUC and carbon storage are addressed only sporadically. The newly developed European Standard EN 16760 "*provides guidance and requirements to assess impact over the life cycle of bio-based products*". In comparison with the methods applied in the LCAs reviewed here, this standard provides more specific recommendations regarding GHG emission consideration. For future LCAs on bio-based products it would be helpful if a database with LCA data on growing, harvesting, pre-treatment and transport of various types of biomass from various regions would become available in LCA databases, allowing producers of bio-based products to focus on collection of data on the conversion into bio-based products and their use and end-of-life phase.

When pasture or agricultural land previously destined for food, feed and fibre production is diverted to biofuel/bioenergy/bio-based products production, the existing demand will need to be satisfied either through intensification of the current production or by bringing non-agricultural land into production elsewhere. The latter case represents **indirect land-use change (ILUC)** and could potentially lead to significant additional greenhouse emissions, if it involves the conversion of high carbon stock land. A main strategy for minimizing ILUC is the promotion of biofuels produced from biomass with low ILUC risks, such as currently unused residues from agricultural crops and forestry production and processing as well as woody and grassy feedstocks for second-generation biofuels production, particularly those produced on degraded and marginal land. It is possible to apply a low-ILUC risk assessment offered by some biomass sustainability certification schemes (RSB and Better Biomass/NTA 8080). In recent years, the estimation of ILUC GHG emissions by global modelling of land use change has received considerable attention with a particular focus on first generation biofuels, i.e. those produced from food and feed crops. Although ILUC modelling is still a relatively young field of expertise and can be further optimised, it will be very difficult to develop ILUC factors that take into account greenhouse gas emissions related to ILUC of different crops that have a high reliability at farm level.

In the current European renewable energy policy framework, biomass used for energy and transport is considered as a carbon neutral source. However, if a tree is harvested, it will take years before a new tree is grown up, creating a temporary **carbon debt**. The payback time of this carbon debt depends on the speed at which the biomass regrows and is longer when old slow growing trees are combusted than when short rotation coppice is used. However, the issue of carbon debt requires further scrutiny: at the level of a single tree carbon debt might occur, but this is not necessarily the case if a larger plot or a whole forest is considered. If for instance a forest's volume grows with 2% per year, it is possible to harvest 2% of the trees while the forest's carbon pool remains intact. Carbon debt is only relevant for bio-based products made out of wood, with a short product lifetime, and is regarded less relevant for bio-based products in general.

Carbon storage in bio-based products has a similar mechanism as carbon storage in forests. Bio-based products with a long lifetime, as for example wooden products, can sequestrate carbon as long as the yearly production volume of the product is larger than the yearly end-of-life removal of the bio-based product. New bio-based products can create new carbon pools, and the longer the product lifetime the later the pool is saturated. The relative contribution of a single product to carbon storage can be expressed in an "Additional Carbon Storage Factor" (ACSF), a concept introduced in this report, based on the IPCC model for harvested wood products, which could be introduced in biomass sustainability schemes or eco-labels.

Cascading use is the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system. In a single stage cascade, biomass is processed into a product and, after its use phase, this product is used once more for energy purposes; in a multi-stage cascade, biomass is processed into a product and this product is used at least once more in material form before disposal or recovery for energy purposes (Vis, Mantau, Allen, & Eds., 2016). Cascading of biomass is not a goal in itself but a means to contribute to resource efficiency targets as well as GHG emission reduction. Cascading use of bio-based products can be stimulated by limiting the energy use of biomass still useable for material application, by promoting design for reuse, avoiding gluing, lamination, chemical bonding if possible and by using used biomass as feedstock instead of fresh biomass. Eco-labelling could be a suitable instrument to indicate that the bio-based product has been designed for reuse.

Bio-based products can be partly or wholly derived from biomass. **Bio-based (carbon) content** measurement methods distinguish between bio-based content and fossil content of a bio-based product. The bio-based content of a product can be produced with sustainable or non-sustainable biomass. Biomass certification schemes can be used to certify that the bio-based content of a bio-based product has been produced in a sustainable way, meeting the sustainability criteria of the applied scheme. Biomass sustainability certification schemes like Better Biomass, RSB, and ISCC-PLUS work with physical segregation and mass balance chain of custody approaches to trace the sustainability attributes of biomass. Mass balance methods allow sustainability attributes to be assigned to any physical batch from a mixture as long as the total mass balance is correct. This means that the certified biomass in hands of the consumer might not be produced sustainably, but it is guaranteed that a similar quantity of biomass has been produced sustainably elsewhere. Contrary to the attribution of sustainability to a certain fraction of the mixture, which seems to be well accepted, attribution of bio-based content to a fossil product is often regarded risky and misleading to consumers. If decided that physical presence of bio-based content in a product is necessary, this requires harmonisation with the more lenient approach of attribution of sustainability to a specific batch in a mixture, as applied in the mass balance chain of custody model. Mass balance methods can be used upstream in the biomass supply chain as long as it only concerns 100% biomass and no fossil products are mixed. As soon as a bio-based product is produced that contains a fossil component as well, a physical segregation method is preferred as this way it is ensured that bio-based content is available in the final product, without the need to determine the bio-based content of each batch by using direct radiocarbon methods.

Conclusions and recommendations

Sustainable biomass production is good practice not only for bioenergy production, but for all applications of biomass including bio-based products, food and feed. Consumers expect that bio-based products are produced from environmentally and socially sustainable biomass, which can be verified with for instance by existing biomass sustainability certification schemes. Next to sustainable biomass production, the issue of calculating the greenhouse gas emission reduction of bio-based products by implementing a proper and standardised LCA approach is regarded highly relevant. The variety of bio-based products and their fossil alternatives, the complexity of production processes and the large variation in available biomass types and their emissions, make this task challenging. The aspect of indirect land use change adds to this complexity, and might not be applied at farm level, but can be used to estimate the ILUC risk of biomass feedstocks. The concept of cascading use can help to improve the environmental performance of bio-based products further and forms the link between bio-economy and circular economy, and could be relevant in eco-labelling. Carbon debt will not play a major role in sustainability assessments of bio-based products. Information on carbon storage is nice-to-have but will not be crucial in sustainability assessments of bio-based products. The link between bio-based content and sustainability lies mainly in the chain of custody of the supply chain. Certification of sustainability and bio-based content need to be harmonised according to the chosen claim; a bio-based product needs to physically contain bio-based content, but this does not exclude schemes that provide other claims not requiring physical presence of biomass in the product, such as "supporting to responsible sourcing of bio-based materials".

Abbreviations

ACSF	Additional Carbon Storage Factor
ASTM	American Society for Testing and Materials
BUE	Biomass Utilisation Efficiency
CC	Cradle to Cradle
CED	Cummulative Energy Demand
CEN	European Committee for Standardization
CEN/TC 411	CEN Technical Committee 411 - bio-based products
CFG	Cradle to Factory Gate
CGR	Cradle to Grave
CO_2	Carbon dioxide, one of the greenhouse gases
EoL	End-of-life
EPFL	École polytechnique fédérale de Lausanne
EU	European Union
EU28	The 28 Member States of the European Union
FAO	Food and Agriculture Organisation
FFU	Fossil Fuel Use
gCO_2-eq	Gram carbon dioxide equivalent
GER	Gross Energy Required
GHG	Green House Gas
HWP	Harvested Wood Product
ILUC	Indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability and Carbon Certification (biomass sustainability certification scheme)
ktonnes	kilotonnes (1 ktonne = 1000,000 kg)
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment method
M tonnes	Megatonnes (1 M tonne = 1,000,000,000 kg
MJ	MegaJoule (unit of energy)
NREU	Non-Renewable Energy Use
NTA8080	Dutch Technical Agreement 8080. Recently renamed to Better Biomass (biomass sustainability certification scheme).
Open-Bio	Opening markets for bio-based products
PED	Primary Energy Demand
RSB	Roundtable on Sustainable Biomaterials (biomass sustainability certification scheme)
UNFCCC	United nations Framework Convention on Climate Change
WWF	World Wildlife Fund

1 Introduction

1.1 Task description

This report shows the setup of Task 3.4. *Incorporation of bio-based (carbon) content methods in sustainability schemes.* In this task, it is investigated whether and how biomass sustainability schemes for energy and fuels can be used to certify bio-based products, and what kind of adaptations are needed, like the incorporation of bio-based (carbon) methods. This will involve the following activities:

- Assessment of main sustainability issues related to the main biomass feedstock used for bio-based products and their coverage by existing schemes for biomass/biofuels and identification of gaps.
- Assessment of current development of standards (e.g. CEN/TC 411/WG 4) and certification schemes (revision of NTA 8080 into Better Biomass[1], ISCC-Plus, etc.) directed to sustainability of bio-based products.
- Review of approaches to determine carbon emission reductions using bio-based products and linking the existing schemes with the methods developed under tasks 3.1, 3.2 and 3.3. *This is interpreted as "review how carbon content methods can be used in sustainability schemes for bio-based products";*
- Development of methods to link environmental and socio-economic sustainability claims provided by biomass production certification schemes (like NTA 8080) to bio-based content. *This is interpreted as advice on how environmental and socio-economic sustainability of bio-based products can be determined in the best way.*

1.2 This report

This report provides an overview of the main biomass feedstocks used for bio-based products (chapter 2), followed by an assessment of main sustainability topics relevant for bio-based products (chapter 3) and an overview of relevant existing initiatives on assessment of sustainability of bio-based products beside the established biomass sustainability schemes (Annex D). Selected topics are investigated and discussed in more detail, i.e. greenhouse gas emission reductions of bio-based products (chapter 4), indirect land use change (chapter 5), carbon storage (chapter 6) and cascading use (7). Links with direct and indirect carbon content methods are discussed in chapter 8 followed by conclusions and recommendations (chapter 9).

The BTG team thanks the Open-Bio consortium for their inputs to this report, and in particular Ortwin Costenoble (NEN), Harmen Willemsen (NEN), Jaap Hooijmans (ECN), Martin Behrens (FNR), Lara Dammer (nova), Luana Ladu (TU Berlin), James Sherwood (University of York), and Nike Mortier (OWS).

[1] Better biomass is the new name of NTA8080. The underlying standard is still NTA 8080, which has been revised and published in 2 parts NTA 8080-1:2015 with sustainability requirements and 8080-2:2015 with chain-of-custody requirements.

1.3 Definition of bio-based products

Broader and narrower definitions of bio-based products coexist. CEN EN 16575 ", Bio-based products - Vocabulary" states:

> *"Bio-based" means "derived from biomass". Bio-based products (bottles, insulation materials, wood and wood products, paper, solvents, chemical intermediates, composite materials et cetera) are products which are wholly or partly derived from biomass.*

Biomass can be used for the sustainable production of food, feed, industrial products, biofuels and bioenergy. All these activities are part of the bioeconomy as defined in the Strategy for "Innovating for sustainable growth: a bioeconomy for Europe"(COM(2012)60):

> *The bioeconomy (…) encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy.*

In this context the definition of bio-based products is actually narrowed down as it apparently does not include food, feed and bioenergy. A more descriptive definition used in the Lead Market Initiative for Europe (COM(2007)860) and its follow up actions is:

> *Bio-based products are made from renewable, biological raw materials such as plants and trees. The market segment chosen for the specific LMI [Lead Market Initiative] includes non-food new bio-based products and materials such as bio-plastics, bio-lubricants, surfactants, enzymes and pharmaceuticals. It excludes traditional paper and wood products, but also bio-mass as an energy source.*

In this context a further distinction is made between "traditional" and "innovative" bio-based products. This distinction is often made when the innovative character of the bio-based sector is emphasised. However, when statistics on the size of the bio-based sector are presented the traditional products are often counted as well.

Furthermore, it is not clear whether "traditional" non-wood bio-based products like for example paper starch, starch adhesives, etc. are excluded from the above definition or not. It will be difficult to distinguish between traditional and modern applications, since there is no clear definition of these terms and what it encompasses. There is no fundamental difference between a traditional and an innovative/modern bio-based product in terms of properties or applications. On the one hand, the distinction could be useful in promoting innovation. On the other hand, such a distinction will be methodologically very difficult as stated above, and will also lead to a partial description of a broad sector.

Biofuels like bioethanol and biodiesel could be classified both as bio-based product and energy source. In this report biofuels are classified as an energy source and excluded from bio-based products, as for biofuels a distinct European biomass sustainability and support regime has been established, while for bio-based products this is not the case.

Typical classes of bio-based products are (European Commission, 2007):

- Fibre-based materials (i.e. for the construction sector or car industry)
- Bio-based plastics and other bio-based polymers
- Surfactants
- Bio-based solvents
- Bio-based lubricants
- Ethanol, other chemicals and chemical building blocks
- Pharmaceutical products including vaccines
- Enzymes
- Cosmetics.

Each class consists of a large variety of products in different stages of development from RTD to full commercial production, covering the process chain from intermediates to final products.

Bio-based products can be bio-based versions of traditional products or novel products with entirely new and innovative functionalities and potential for new and existing markets. Moreover, bio-based products can be either biodegradable or non-biodegradable. The only characteristic that all bio-based products have in common is that they are partly or wholly made of biomass.

In this report bio-based products refer to non-food products derived from biomass (plants, algae, crops, trees, marine organisms and biological waste from households, animals and food production). Biomass used as an energy source or as a biofuel is excluded.

In this report no difference is made between traditional and innovative bio-based products, unless this is clearly specified in the text.

2 Overview of feedstock types used for bio-based products

The bioeconomy includes food, feed material, fuel and energy applications of biomass. The total biomass supply and demand in the bioeconomy of the EU28 are estimated by (Ronzon, Santini, & M'Barek, 2015), see Figure 1.

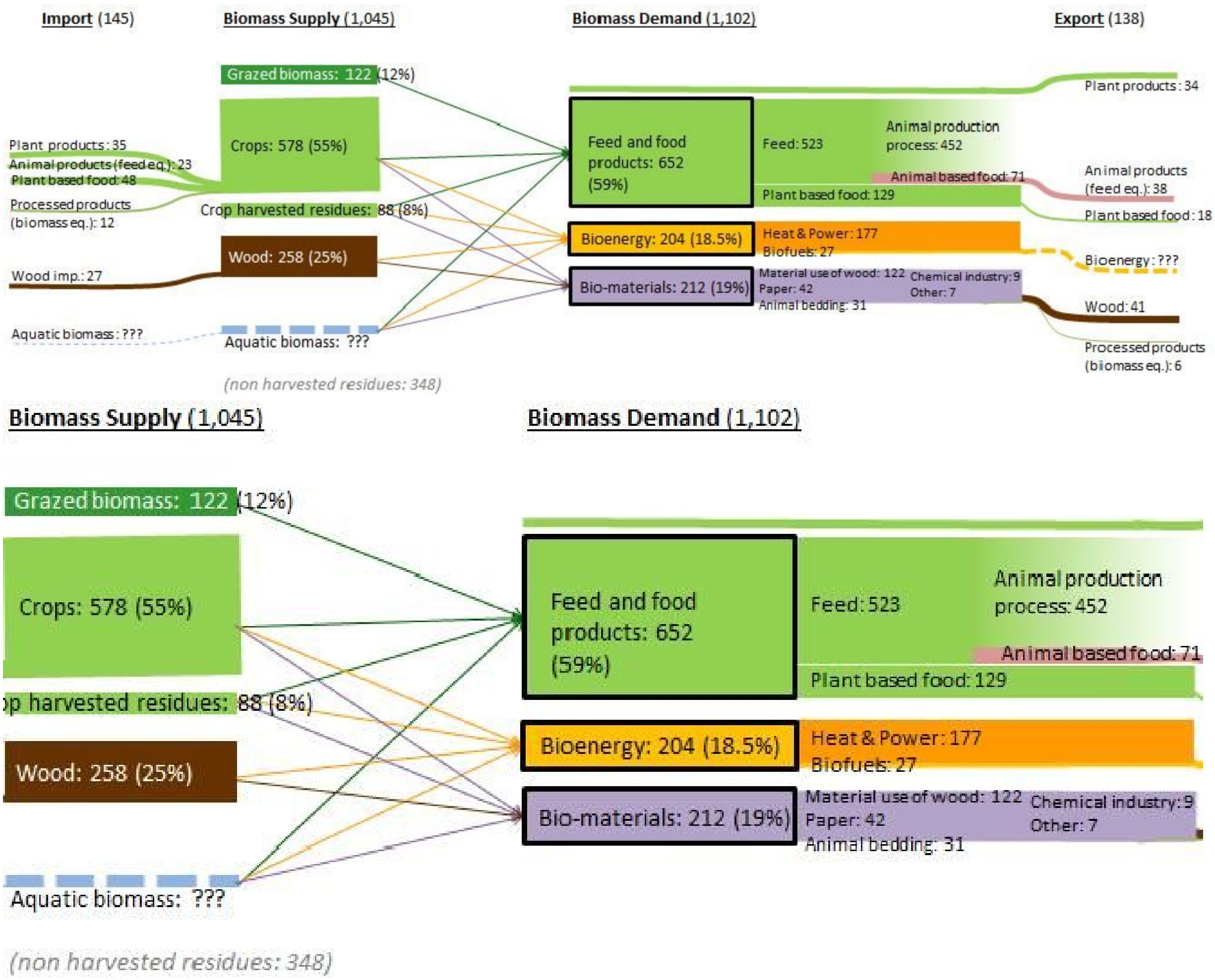

Figure 1: Preliminary biomass balance in the European Union (million tonnes of dry matter, EU-28, 2013) Source: (Ronzon et al., 2015)

It shows that feed and food are the largest biomass users, followed by bio-materials and biofuels. Within the category bio-materials, wood is the most important feedstock, providing 122 M tonnes for raw materials for use in wooden products and paper. The chemical industry (9 M tonnes dry materials) and other (7 M tonnes of dry material) are relatively modest consumers of biomass. However, these categories represent the category of innovative bio-based products that are targeted in Open-Bio.

An indicative overview of the amount of non-wood biomass that is used for the production of bio-based products and their current uses in food/feed and energy is provided in Table 2. It shows that food/feed is the dominant application of non-wood biomass. Materials and energy have roughly an equal share of each 6% of non-wood biomass use in the EU27. It is interesting to observe that 11.6 M tonnes of sugar and starch biomass are used for material use, which is 70% of the total material use of non-wood biomass (see Figure 2). Another 19% of material use is with oil bearing crops. It indicates that the food-versus-fuel debate that is associated with first generation biofuels is equally relevant for many bio-based products.

Table 2: Overview of non-wood biomass types and their application in the EU27 (in million tonnes)

Type of biomass	materials	food/feed	energy	total	% of total biomass
Lignocellulosic biomass	1.9	0.2	0.0	2	1%
Sugar and starch biomass	11.6	191.6	13.5	217	82%
Oil bearing biomass	3.1	42.2	1.9	47	18%
Total	16.5	234.0	15.3	266	100%
% of total biomass	6%	88%	6%	100%	

Source: Derived from (Carus, 2012).

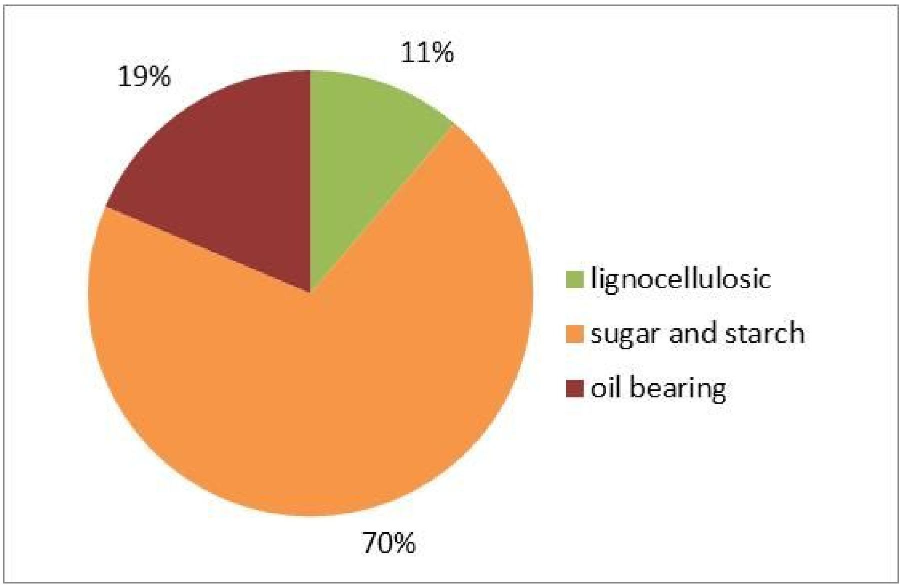

Figure 2: Origin of non-wood biomass used for material application in the EU27. Source: Derived from Table 2 (Carus 2012).

In the next sections the biomass sources relevant for bio-based products are discussed in more detail.

2.1 Sugar and starch biomass

Table 3 shows that maize, potatoes and wheat are the most important starch suppliers used in bio-based products. Food/feed is the dominant use of sugar and starch biomass. The European starch industry processes about 8.9 million tonnes per year of starch into applications like corrugating and paper making (28% of total industrial starch use), pharma & chemicals (6%) and other non-food (4%), adding up to a total of 38% material use of starch within the starch industry[2]. Other applications include processed foods (30%) as well as confectionary and drinks (32%). Outside the industry starch is mainly used in food/feed applications, with the exception of maize that is used in considerable quantities for energy (biogas & ethanol) production as well.

Table 3: The use of sugar and starch biomass in materials, food/feed and energy applications in the EU27 (ktonnes/year).

Sugar and starch biomass	Materials	Food/feed	Energy
Maize	3.880	29.219	5.791
Potatoes	2.631	50.000	0
Wheat	1.866	60.540	856
Cassava	1.015	10	0
Barley	872	27.888	291
Sugar beet	858	11.157	5.149
Rye	193	2.905	774
Triticale	144	4.572	96
Sugar cane	124	2.441	495
Rice (unhulled)	15	2.916	0
Total	11.598	191.648	13.452
	5%	88%	6%

Source: (Carus, 2012)

As shown in Figure 3 glucose is the main building block for a variety of bio-based polymers. Sugar and starch crops are the main suppliers of glucose. The European market volume of all bio-based plastics is estimated at 260 ktonnes in 2008 (ERRMA 2012 in Carus (2012)). In 2011 around 560 ktonnes of bio-based polymers (starch based and other biomass sources) were produced in Europe, the bio-based content in bio-based polymers is estimated at 300 ktonnes in 2011 (calculated with data from nova 2013) [3]. Compared to the total material use of 11.6 M tonnes of sugar and starch biomass, this number of 300 ktonnes is relatively small (approximately 2.5%).

[2] Source: http://www.aaf-eu.org/european-starch-industry/
[3] Calculated with data from (Dammer, Carus, Raschka, & Scholz, 2013). Figure 4 of that report shows roughly 2.8 M tonnes of bio-based polymers production world wide combined with a European market share of 20% according to Figure 6. Figure 5 shows data on bio-based content.

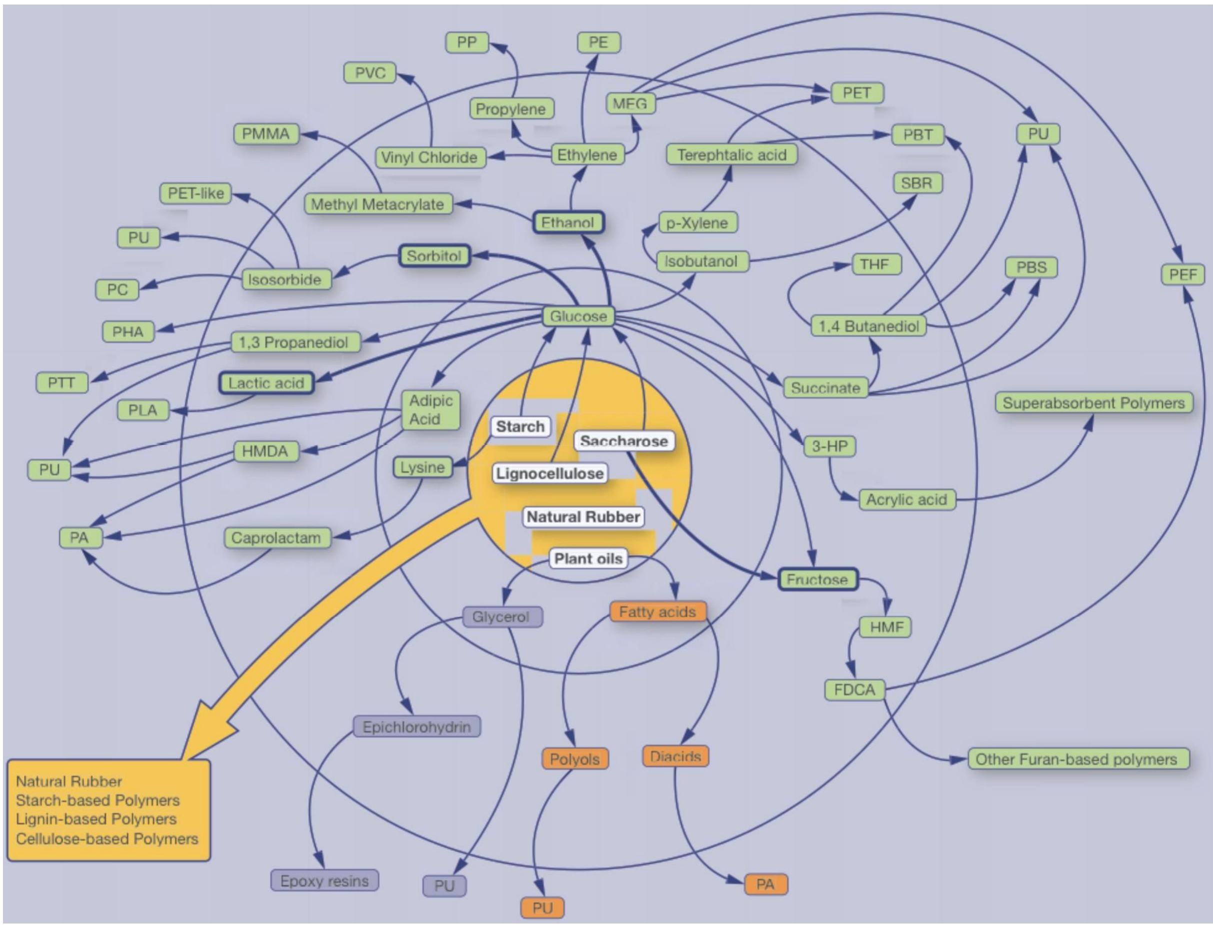

Figure 3: Illustration of possible pathways to produce bioplastics and biopolymers. Source: (nova Institute, 2013)

2.2 Oil bearing biomass

Table 4 shows the use of oil bearing biomass in the EU27 (Carus, 2012). Food and feed applications are with 91% the most dominant application. Especially the protein rich soy beans are relevant in food/feed applications. Around 5% of the oil bearing biomass is used for material applications, with oil palm fruit as the dominant material application. Palm oil has many oleochemical applications, and is used e.g. for personal care products, cosmetics, soaps, lubricants, polyols for polyurethane production etc. Biodiesel production is the main energy application of the oil bearing biomass.

Table 4: The use of oil bearing biomass in materials, food/feed and energy applications in the EU27 (ktonnes/year).

oil biomass	Materials	Food/feed	Energy
Oil palm fruit	1.392	4.617	928
Linseed	281	2	0
Soy beans	229	26.567	239
Sunflower seeds	210	4.457	58

oil biomass	Materials	Food/feed	Energy
Castor oil seed	145	0	0
Rape seed	71	6.449	639
Total	2.328	42.092	1.864
% of total	5%	91%	4%

Source: (Carus, 2012)

2.3 Non-wood lignocellulosic biomass and rubber

Table 5 shows the use of non-wood lignocellulosic materials and rubber in the EU27 (nova 2012). In this feedstock group the material application is dominant.

Table 5: The use of non-wood lignocellulosic biomass and rubber in materials, food/feed and energy applications in the EU27 (ktonnes/year)

lignocellulosic biomass	Materials	Food/feed	Energy
Natural rubber	938	0	0
Coconut	754	68	0
Cotton (lint)	710	0	0
Flax fibres (straw)	117	0	0
Bamboo	61	133	0
Sisal and similar fibres	16	0	0
Hemp fibres (straw)	11	0	0
Jute and similar fibres	8	0	0
Cotton (seed)	0	70	0
Total	1861	203	0
	90%	10%	0%

Source: (Carus, 2012)

The energy application is virtually absent, due to the high value of the product. Food/feed applications are limited to the non-lignocellulosic edible parts of the crop. Most materials are used in “traditional” bio-based applications like rope manufacture. Regarding modern biomass applications the use of natural fibre reinforced composites in the automotive industry is eye-catching. According to nova (2013) about 50 ktonnes non-wood natural fibres (like flax, kenaf, hemp, jute, coir, sisal and recycled cotton fibres) were used in the European automotive production in 2012 (2.6% of total material use).

3 Overview of sustainability issues

3.1 Introduction

Bio-based products are wholly or partly derived from biomass and could provide a green alternative for fossil/mineral products. Until 2005 biomass for energy and biofuels was generally seen as green as well. However, the increased production and import of palm oil associated with unsustainable land use change caused a strong call to verify the sustainable production of palm oil and other biomass types. Since then, obligatory sustainability certification has been introduced for biofuels and liquid biomass that are accounted to renewable energy targets within the EU. In addition voluntary sustainability schemes have been developed for solid and gaseous biomass. These schemes generally cover greenhouse gas emission savings of the supply chain as well as additional environmental and social sustainability criteria of the biomass production. Additional topics like indirect land use change (ILUC), carbon debt, cascading of biomass have been heavily debated in recent years and are gradually being translated into requirements in the existing certification schemes.

Research on consumer perception and acceptance of bio-based products (Meeusen, Peuckert et al 2014) shows that consumers expect that bio-based products are produced from environmentally and socially sustainable biomass. Also policy makers stress the need for sustainable biomass production for bio-based products, next to bioenergy and biofuels. "The Bioeconomy Strategy and its Action Plan" (COM(2012)60) aims to pave the way to a more innovative, resource efficient and competitive society that reconciles food security <u>with the sustainable use of renewable resources for industrial purposes</u>, while ensuring environmental protection. Furthermore, in (COM(2012)14/2) *For a European Industrial Renaissance* the European Commission has made *"granting access to sustainable raw materials at world market prices for the production of bio-based products"* as one of its priorities. For producers of bio-based products it is worth to address sustainability issues properly to convince their consumers, to promote their products and to avoid the risk of negative public perception.

In this chapter the relevance of the main sustainability issues for bio-based products is discussed in more detail. The following topics will be addressed:

- Sustainable biomass production (§ 3.2)
- Greenhouse gas emission reduction (§ 3.3)
- Indirect land use change (ILUC) (§ 3.4)
- Carbon debt (§ 3.5)
- Carbon storage (§ 3.6)
- Cascading of biomass (§ 3.7)
- Bio-based content and chain of custody (§ 3.8).

Each sustainability topic is introduced and evaluated on its relevance for bio-based products. Subsequently, it is shown if and how existing sustainability schemes address these topics. Three sustainability schemes (Better Biomass, RSB and ISCC) have been selected for this purpose as these schemes cover multiple biomass types and are adjusted to cover bio-based products next to bioenergy and biofuels. For each topic a short outlook is provided on how these themes are expected to be covered in the near and medium future. In section 3.9 the findings are summarised, after which the selected topics have been investigated in more detail in chapters 5 to 9.

3.2 Sustainable biomass production

Introduction

As shown in chapter 2 bio-based products are made of sugar and starch, oil bearing biomass and lignocellulosic biomass. Existing biomass sustainability certification schemes can be adjusted to certify the sustainable production of biomass for bio-based products as well. The Better Biomass (NTA8080:2015), ISCC-PLUS and RSB have already implemented such adjustments. These schemes cover themes like biodiversity, soil quality, water quality, social well-being of workers and communities, etc. A general introduction of these schemes can be found in the Annex A. A summary of the coverage of main topics is given below.

Sustainable production of biomass in existing sustainability schemes

A comparison of the most relevant topics are summarised in Table 6, which is based on Van Dam, Junginger, & Faaij (2010); more details can be found in Annex B. Other useful sources for comparison of sustainability schemes are www.standardsmap.org[4], and WWF (2013).

Table 6: Overall appreciation of the coverage of sustainability topics beyond RED requirements in NTA8080, RSB EU RED and ISCC

Sustainability topics covered	Better Biomass	RSB EU RED	ISCC-PLUS
Biodiversity	++	++	+
Soil quality and quantity	+	+	-
Water quality and quantity	+	+	+
Other environmental topics	++	++	+/-
Social well-being workers	+	++	+
Well-being local communities	++	++	+

Note: For explanation of the appreciation (++,+,+/-,-) see Annex B.
Source: based on Van Dam, Junginger, & Faaij (2010)

[4] Exact link to comparison of RSB, NTA8080 and ISCC: http://www.standardsmap.org/compare?standards=172,55,43&standard=0&shortlist=172,55,43&product=Biomass&origin=Any&market=Any&cbi=78:78:754

Outlook

A trend toward further extension of the extended sustainability schemes to comprise all applications of biomass including food and feed can be observed. Awareness is growing that ideally speaking, all biomass regardless of its final destination should be produced in a sustainable way. Certification schemes like RSPO (palm oil) and Bonsucro (sugarcane) can be used to certify the product regardless of its final application. The Dutch Sustainable Biomass Commission (2014) advised to investigate whether sustainability criteria for bioenergy could also be applied for biomass used in food production. Fritsche & Iriarte, (2014) observe that there is still a lack of coherence in intersectoral approaches that needs to be overcome, acknowledging all types of biomass for any purpose. This trend towards sustainability requirements for all land-based biomass sources could eventually lead to movement from (time and effort consuming) specific sustainability certification schemes toward general applicable legislation covering sustainability topics comprehensively.

3.3 GHG reduction

Introduction

Greenhouse gas emission reduction is one of the main environmental benefits of bio-based products and should therefore be addressed properly. The Open-Bio project shows that impact of bio-based products on climate change/CO_2 emission savings are regarded very important[5] by NGOs (Meeusen, Ge, Peuckert, & Behrens, 2015) and public procurers (Peuckert & Quitzow, 2015) and regarded relevant[6] by consumers too (Sijtsema, Onwezen, Reinders, Dagevos, & Meeusen, 2015). The greenhouse gas reduction of energy applications of biomass can be calculated relatively easy because the number of fossil alternatives is limited. In the Renewable Energy Directive (2009/28/EC) and the Communications on solid and gaseous biomass (COM(2010)11), (SWD(2014)259) and (Giuntoli, Agostini, Edwards, & Marelli, 2015) standard values have been established for fossil heat and electricity generation that are applied by all sustainability schemes that comply with the Renewable Energy Directive. This makes it possible to compare the GHG emission reduction of different pathways for bioenergy and biofuels production in a coherent way. Calculating the GHG emission reduction of bio-based products is however more difficult than those of bioenergy and biofuels options because (1) production processes are more complex (2) often more fossil alternatives to the bio-based product are available and (3) validated GHG emissions of multiple fossil alternatives are not always available.

GHG emission reduction of bio-based products in existing sustainability schemes

ISCC and RSB offer additional voluntary tools for GHG emission reduction calculations that can be selected as an add-on but are not required for certification. NTA8080 does not offer this option but requires that producers have insight in the carbon emissions related to their bio-based product. See Table 7 for an overview.

[5] Mentioned in top 3 of relevant aspects of bio-based products

[6] Not mentioned in top 3 of relevant aspects of bio-based products. Consumers regard aspects like health impact, biodegradability and recyclability more important.

Table 7: Specific criteria on GHG reduction for bio-based products in NTA8080, RSB and ISCC

Topic	NTA8080	RSB	ISCC-PLUS
GHG emission calculation	Yes	Optional	Optional
GHG emission reduction calculation	No	Optional	Optional
Minimum GHG emission reduction	No	Optional (min. 10% if reported)	No

Source: own investigation BTG.

Better Biomass (NTA8080-1:2015) requires that the organisation that seeks certification shall have access to the data on the own greenhouse gas emissions and the greenhouse gas emissions in the preceding chain. The organisation can use the greenhouse gas emission calculation methodology as used in the Renewable Energy Directive (as presented in NTA8080-1:2015, Annex C). No requirements are set on the net greenhouse gas emission saving for the time being, since no (unambiguous) fossil reference situations are available. Validated fossil reference values are often not available and in many situations the fossil reference cannot be determined unambiguously.

RSB allows voluntary claims on GHG emission reduction of the bio-based product provided that a significant (10% or more) reduction in lifecycle GHG emission is demonstrated, and that the RSB Greenhouse Gas methodology or any LCA methodology in conformance with ISO 14040:2006 or the GHG Protocol[7] is applied. The total lifecycle greenhouse gas emissions of the bio-based products have to be compared to reference life cycle greenhouse gas emissions corresponding to an equivalent product derived from petroleum or any fossil origin. Although the LCA calculation method has to meet certain requirements, the user has freedom in the selection of the equivalent fossil derived product to compare with.

ISCC PLUS provides a voluntary add on[8] to calculate the greenhouse gas emission savings of the bio-based product. The GHG emissions of the production can be calculated in a similar way as done in the Renewable Energy Directive. If applicable, the final interface can calculate the GHG saving potential compared to the conventional material. Reference is made to an ISCC list of emission factors that should be used to avoid cherry picking of emission factors. However, besides emission factors of various agricultural inputs, conversion inputs, fuels etc. this list contains no GHG emissions of conventional products, yet. No further guidance is given on how to determine the GHG emissions of the conventional product, meaning that the producer of bio-based products has to determine its own calculation (method) to determine the GHG emissions of the conventional materials or if free to select data from available databases with standard GHG emission values.

[7] See http://www.ghgprotocol.org/
[8] ISCC PLUS add-on 205-01 "GHG Emissions"

It is concluded that ISCC PLUS and RSB allow claims on GHG reduction of bio-based products, but that rather generic guidance is provided on how to perform the GHG emission reduction calculation. The methods will probably be improved when the demand for these GHG calculations will rise.

Outlook

A key challenge is that the variety of bio-based products and alternative fossil applications is very diverse. The EN 16760:2015 standard on Life Cycle Assessment of bio-based products could play a role to cover the gap in guidance that exists in the current sustainability certification schemes. This will be further addressed in chapter 4. It can be questioned whether this standard provides sufficient guidance to achieve LCAs that are comparable with each other and can serve as benchmark. The coming years more research work can be expected, for instance in the frame of the Horizon 2020 call “BB-01-2016: Sustainability schemes for the bio-based economy”. Experiences in the building sector show that it is possible to build a database with the GHG performance of a large variety of building materials. See for instance the DGBC Materialentool of the Dutch Green Building Council (DGBC)[9]. It might be possible to establish such a database to collect and share LCA data of bio-based products as well.

A more detailed assessment of the role and application of LCA of bio-based products and evaluation of GHG emission savings is presented in chapter 4.

3.4 Indirect land use change (ILUC)

Introduction

When pasture or agricultural land previously destined for food, feed and fibre production is diverted to biofuel/bioenergy/bio-based products production, the existing demand will need to be satisfied either through intensification of the current production or by bringing non-agricultural land into production elsewhere. The latter case represents indirect land-use change (ILUC) and could potentially lead to significant greenhouse emissions, if it involves the conversion of high carbon stock land. It is impossible to trace the direct relation between the use of land plot A and indirect conversion of land plot B. However, generic “ILUC factors” have been developed that put a greenhouse gas emission reduction penalty on certain crops. The question whether it is possible to quantify ILUC factors with sufficient accuracy is still subject to scientific debate. Nevertheless, in the ILUC proposal of the European Commission (COM(2012)595), ILUC emissions were introduced for cereals and other starch rich crops, sugars and oil crops. Especially the ILUC factor of oil crops of (55 gCO_{2eq}/MJ) would have shrunk the reduction of greenhouse gas emissions achieved by biodiesel below the threshold of 35% emission reduction, directly threatening the biodiesel industry. However, the finally approved ILUC Directive (2015/1513) contains only a reporting

[9] See http://www.dgbc.nl/ and https://www.milieudatabase.nl/

obligation for Member States and the Commission, and biofuel producers do not have to take into account ILUC factors in their GHG reduction calculation.

ILUC is relevant for bio-based products made of sugar, starch and especially oil crops. One could argue that traditional bio-based products (like various starch based products) have already been grown for decades and do not cause indirect land use change anymore, provided that their yearly production rate is more or less stable. New bio-based products cause ILUC the same way as first generation biofuels do. This could affect the degree to which bio-based products from sugar, starch and oil crops could contribute to mitigating climate change.

ILUC in existing certification schemes relevant for bio-based products
RSB, Better Biomass (NTA8080-1:2015) and ISCC-PLUS have not implemented ILUC factors for agricultural biomass to compensate for indirect emissions elsewhere, as was proposed in EC proposal COM(2012)595 for the “ILUC Directive”. RSB and NTA8080 stress the importance of this matter in their documentation, but see no possibilities to apply ILUC factors on farm level. Instead, RSB and NTA8080 promote low ILUC biomass through the use of a “Low Indirect Impact Biofuels” (LIIB) approach that is being developed by WWF, Ecofys and EPFL.

Outlook
The ILUC proposal has led to an intensive discussion on the possibility to use ILUC factors. Current sustainability schemes have not implemented ILUC factors and it can be questioned whether the scientific basis will be improved in such a way that the use of ILUC factors will be possible in a scientifically sound way. In the coming years research and monitoring activities will continue, see for instance the recent GLOBIOM report (Valin et al., 2015).

It is currently uncertain to what extent first generation biofuels will be promoted after 2020. According to the recent Climate Package (COM(2014)15) the Commission does not think it appropriate to establish new targets for renewable energy or the greenhouse gas intensity of fuels used in the transport sector or any other sub-sector after 2020. This would reduce the direct need to further develop binding sustainability criteria for biofuels for transport.

More information on the topic of ILUC in the context of bio-based products is provided in chapter 5.

3.5 Carbon debt

Introduction
In the current European renewable energy policy framework, biomass used for energy and transport is considered as a carbon neutral source. However, if a tree is harvested, it will take years before a new tree is grown up, creating a temporary carbon debt. Moreover, if biomass

is combusted instead of natural gas, the direct CO_2-emissions are even higher because wood is a more carbon intensive fuel than natural gas. The payback time of this carbon debt depends on the speed at which the biomass regrows and is longer when old slow growing trees are combusted than when short rotation coppice is used. Therefore, although bioenergy is carbon neutral on the long term, on the short term this is not necessarily the case. NGOs have put the issue of carbon debt on the agenda especially in relation to the use of whole trees in wood pellet production for co-combustion in coal power plants. See for instance Greenpeace (2011).

However, the issue of carbon debt requires further scrutiny: at the level of a single tree carbon debt might occur, but this is not necessarily the case if a larger plot or a whole forest is considered. If for instance a forest's volume grows with 2% per year, it is possible to harvest 2% of the trees while the forest's carbon pool remains intact. In Europe the forest volume is growing already for decades and only 70.5% of the annual growth of the forest is actually harvested (Forest Europe, 2015), which suggests there is still space for harvest for bioenergy production or other applications without the occurrence of carbon debt at European level. However, one also could argue that each m^3 of wood used for bioenergy, reduces this growth of carbon stock of the forests and thus creates carbon debt. However, in the long term the sequestration capacity limit of the forest will be reached. Moreover, absence of forest management involves an additional risk of pests, diseases and forest fires that could reduce the carbon stock again.

For non-wood bio-based products the carbon debt discussion is not relevant. It could, however, be relevant for bio-based products made of wood, especially for bio-based products having a short product lifetime that are converted into energy shortly after its use.

Carbon debt in existing certification schemes relevant for bio-based products
Currently, the issue of carbon debt is not explicitly included in sustainability certification schemes. The latest NTA8080: explicitly addresses the reasons for not including it: "*When developing this NTA, the drawing up of tools in order to visualise carbon debt was attempted, such as drawing up a 'negative' list or drawing up some sort of risk matrix that would show the degree of carbon debt occurring. Creating such tools proved to be difficult, all the more so because risks can also be prevented by setting other sustainability requirements (e.g. in the field of biodiversity). The fact that carbon debt is not considered in this NTA does not mean that changes to carbon stocks are not addressed. This NTA contains various requirements, including requirements for calculating the greenhouse gas emissions including changes to carbon stocks due to [direct] changes in land use, the excluding of land use changes in areas with high carbons stocks, and requirements as regards soil quality".*

Outlook
It is expected that rational forest management will play an important role in activities to mitigate climate change. This will probably not lead to a ban on harvest of wood for energy. The European Forest Sector Outlook Study II (UNECE & FAO, 2011) states that *"to maximise the forest sector's contribution to climate change mitigation, the best strategy is to*

combine forest management focused on carbon accumulation in the forest (longer rotations and a greater share of thinnings) with a steady flow of wood for products and energy (Maximising biomass carbon scenario). In the long term however, the sequestration capacity limit of the forest will be reached, and the only potential for further mitigation will be regular harvesting, to store the carbon in harvested wood products or to avoid emissions from non renewable materials and energy sources".

3.6 Carbon storage

Introduction

Bio-based products with a longer lifetime, as for example wooden products, can sequestrate carbon as long as long as the production volume of the product is larger than the end-of-life removal of the bio-based product. New bio-based products can create new carbon pools, and the longer the product lifetime the later the pool is saturated. Own calculations based on Decision 529/2013/EU are presented in Figure 4 that presents the development of a simple carbon pool in which each year 1 kg of carbon is produced with product lifetimes of 1, 10 and 50 years.

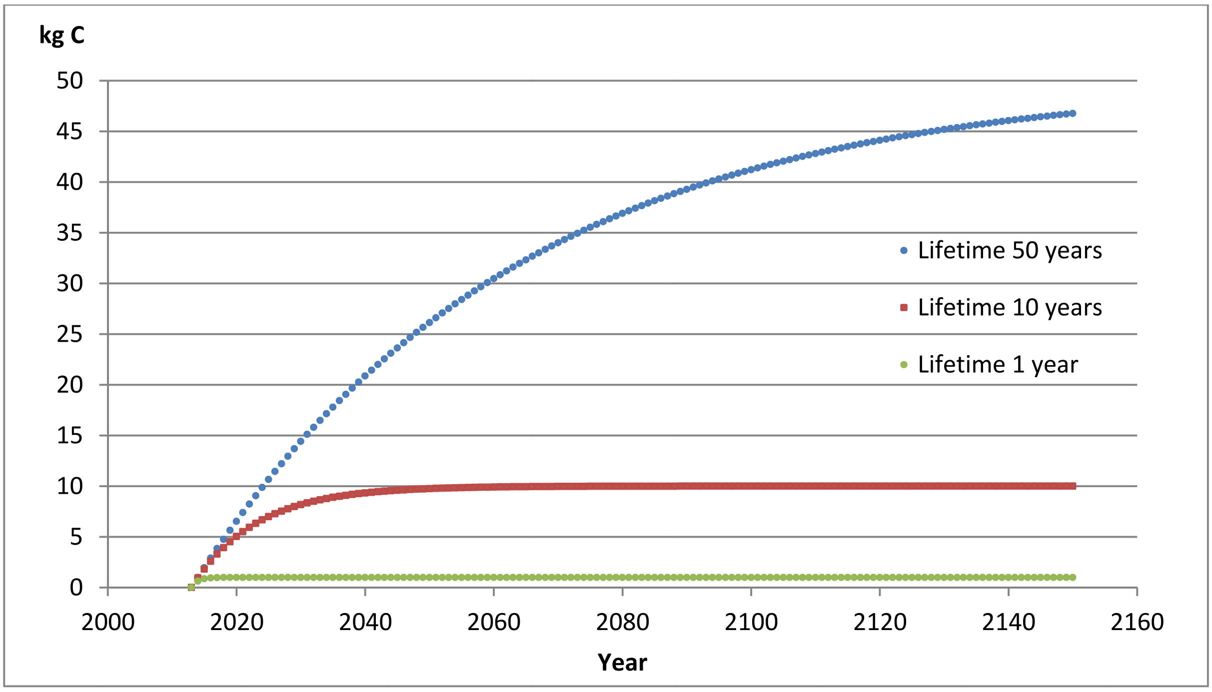

Figure 4: Carbon storage (kg) over time in case each year a bio-based product with carbon content of 1 kg is produced with an average lifetime of 1, 10 and 50 years, respectively. Source: own calculations based on Decision 529/2013/EU.

This way an extra carbon pool is created outside the forest. Currently carbon storage in bio-based products or harvested wood products is neither measured systematically nor valued in financial terms. The IPCC Good Practice Guidelines (IPCC, 2006) provide countries the methods to include carbon storage in “harvested wood products” (HWP) in their national greenhouse gas inventory report that has to be submitted to UNFCCC each year. Most countries, however, currently do not consider carbon storage in harvested wood products and simply take the carbon stock change as zero. The European Commission promotes the accounting of harvested wood products by Decision 529/2013/EU and obliges member states to apply the accounting rules of UNFCCC on harvested wood products, without the obligation to implement them in the national inventory reports. The decision provides standard half-life values for paper, wood panels and sawn wood and allows the use of subdivisions of these categories and country-specific half-life factors. For modern bio-based products with a long lifetime, carbon storage could be an extra environmental benefit that could be used for its promotion. However, it is unlikely that this environmental benefit will be appreciated in financial terms on the short term.

Carbon storage in existing certification schemes relevant for bio-based products
Carbon storage is currently not addressed in existing certification schemes relevant for bio-based products, because it is not a relevant issue for biofuels and bioenergy applications.

Outlook
Carbon storage of harvested wood products can be implemented in National Emissions Inventory (NEI) that countries have to supply to UNFCCC on a yearly base. One issue is that according to Decision 529/2013/EC the carbon storage is allocated to the country that produced the biomass, even if the product and subsequent carbon storage is produced and used in another country. This makes it less attractive for member states to promote carbon storage from imported feedstock. The overall carbon storage impact of a bio-based product depends on the amount of the bio-based product that is already on the market. However, it is possible to develop a carbon storage indicator for individual products as shown in a case study on wooden pallets (Vis, Reumerman, & Gärtner, 2014).

A proposed methodology to determine the impact of carbon storage in bio-based products is presented in chapter 6.

3.7 Cascading use of biomass

Introduction
The literature includes a wide range of different definitions of the term cascading use (Vis, Mantau, Allen, 2016). In the first place the term cascading use refers to subsequent material uses of biomass followed by final conversion into energy. Secondly, it is used in relation to biorefineries, stressing the possibilities to produce multiple products out of one biomass source; this is also referred to as coproduction. Finally the term it is used to express that biomass should be used in such way that it creates the highest value, usually economic value added, but this could be supplemented with indicators for social and environmental value. Following (Vis, Mantau, Allen, 2016), in this report only the subsequent material use of biomass will be called cascading use.

Cascading as the subsequent use of biomass is particularly relevant in the wood sector. Wood can be used first for timber, subsequently in particle boards and finally for energy generation (See Figure 5). A further distinction could be made into a *single stage* cascade in which biomass is processed into a product and this product is used once more for energy purposes; and a *multistage* cascade in which wood is processed into a product and this product is used at least once more in material before disposal or recovery for energy purposes. This way resource efficiency is achieved as less biomass is needed to achieve the same amount of products.

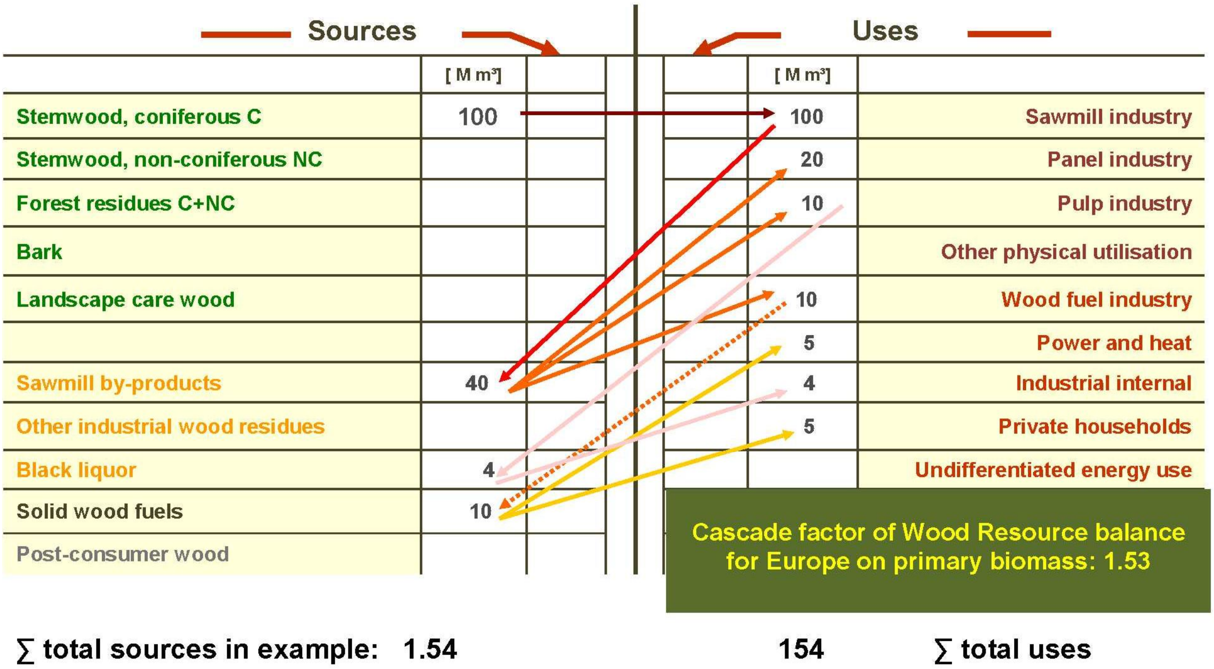

Figure 5: Example of cascading in time. Source: Mantau (2011)

The waste hierarchy established in the Waste Framework Directive (2008/98/EC) illustrates the cascade for secondary raw materials, by establishing the waste management options in the following order of preference: prevention, reuse, recycling, energy recovery and disposal. However, as long as a product is not in the waste phase, no requirements regarding cascading use can be imposed. Companies in the wood sector that use cheaper types of biomass such as waste wood in the particle board industry experience competition from the bioenergy sector. The growing demand for bioenergy could result in shorter cascades, for instance if material formerly used for particle production is combusted directly.

Coproduction is another way to achieve resource efficient use and can be combined with cascading in the sense of subsequent material use of biomass. Iffland et al. (2015) has developed a Biomass Utilisation Efficiency (BUE) index that expresses this aspect. Coproduction alone can result in a BUE of 1, only cascading can help to increase the BUE to levels >1. It is noted that the resource efficiency does not depend on the number of coproducts that is produced, but on the percentage of initial biomass that is used.

Value maximisation, i.e. the wish to create maximum value out of biomass over the whole life cycle of a material is often expressed in “ladders” and “pyramids”. For example, within the Netherlands the bio-based pyramid presented in LNV (2007) is widely known and used to promote the applications with the highest value added first (see Figure 6). Internationally this bio-based pyramid ranking pharmaceuticals (fine chemicals), food, feed, (bulk) chemicals, fuel and fire is known as the five F’s.

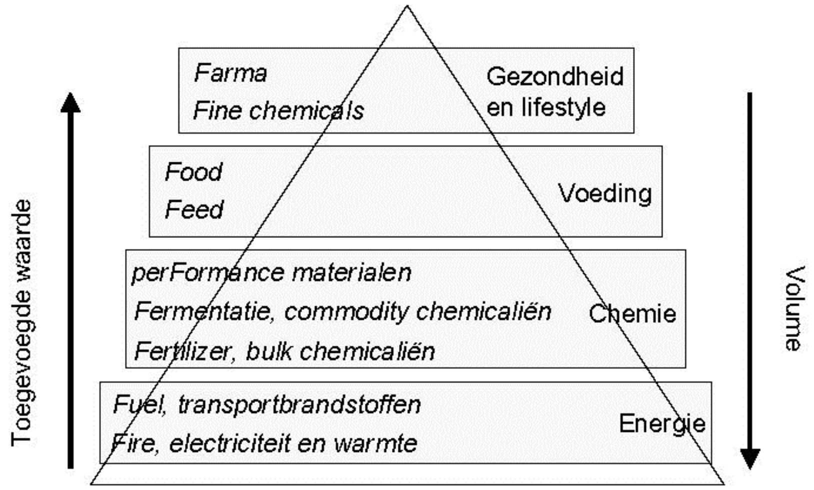

Figure 6: The bio-based pyramid. Source: LNV (2007)

In an undisturbed market, biomass will be used in the application with the highest economic value added, which is usually food and feed, and in some cases pharma and fine chemicals. The pyramid also reflects the food-versus-fuel debate, by putting food higher in the hierarchy than fuels, which is usually (but not necessarily always) true from the perspective of economic value added, but in fact is a moral statement. Some proponents of bio-based products use these pyramids as a way to promote bio-based applications over energy applications. However, value optimisation of concrete biomass value chains depends on many economic, environmental and social aspects and cannot be fixated in a one-size-fits-all ladder or pyramid. In fact, for each biomass type and economic and environmental situation, a separate pyramid or ladder could be developed. It depends on the definition of value what application should be preferred. Value could for instance be defined by policy targets for resource efficiency, renewable energy and carbon emission reduction or a combination of them. In order to do so it is necessary to quantify the impact of a situation with cascading compared to a reference situation without or with less cascading. Vis et al. (2014) developed a calculation method to estimate resource savings, greenhouse gas reductions and economic value impacts of cascades that could be used for evaluation of bio-based products as well.

Cascading in existing sustainability schemes relevant for bio-based products

Cascading is part of the NTA8080-1:2015 standard in the form of a reporting obligation on resource efficient use of biomass. The organisation that seeks certification has to describe the choice of the used biomass and measures that are taken to use the biomass in the most resource efficient way possible. Other schemes do not cover cascading use yet.

Outlook

On European policy level, the issue of cascading is addressed in various plans like the Action Plan for a circular economy (COM(2015)614), the EU Bioeconomy Strategy Action Plan (COM(2012)60), the Roadmap to a Resource Efficient Europe (COM(2011)571) and the 2030 policy framework for climate and energy (COM(2014)15). In short the European Commission recognises that *"an improved biomass policy will also be necessary to (…) allow for fair competition between the various uses of biomass resources in the construction sector, paper and pulp industries and biochemical and energy production"* (COM(2014)15). Furthermore, according to its Communication on an Industrial Renaissance (COM(2014)14, 2014) the European Commission will pursue priority to *"Bio-based products: granting access to sustainable raw materials at world market prices for the production of bio-based products. This will require the application of the cascade principle in the use of biomass and eliminating any possible distortions in the allocation of biomass for alternative uses that might result from aid and other mechanisms that favour the use of biomass for other purposes (e.g. energy)*. The study on the optimised cascading use of wood (Vis et al., 2016) commissioned by DG Growth investigates the aspects of competition between material and energy sectors due to bioenergy subsidies with specific focus on the particle board industry. Although it is difficult to prove the impacts of bioenergy subsidies on material application of biomass, it is expected that the European Commission will take into account cascading when formulating renewable energy policies for the period 2020-2030. The European Commission already has to report on among others cascading aspects related to the implementation of the Renewable Energy Directive (2009/28/EC) (art. 23.5.e): *„In its reports, the Commission shall, in particular, analyse: […] the availability and sustainability of biofuels made from feedstocks listed in Annex IX, including an assessment of the effect of the replacement of food and feed products for biofuel production, taking due account of the principles of the waste hierarchy established in Directive 2008/98/EC and the biomass cascading principle, taking into consideration the regional and local economic and technological circumstances, the maintenance of the necessary carbon stock in the soil and the quality of soil and ecosystems"*. In this directive the "cascading principle" is not defined and requires further elaboration by the European Commission.

More information on the topic of cascading use and bio-based products can be found in chapter 7.

3.8 Bio-based content and chain of custody

Introduction

Bio-based content is not a measure of sustainability, as the bio-based content does not say anything about the sustainability of the production of the biomass, logistics and conversion processes. It just states how much of the bio-based product is derived from biomass either produced sustainably or not. Some sustainability schemes like NTA8080, ISCC and RSB can be used to certify that the biomass part of the bio-based product has been grown sustainably. Please refer to Annex A and B for an introduction and comparison of these schemes. It is good to keep in mind that the origin and sustainability of the fossil part of the bio-based product is out of the scope of the biomass sustainability schemes.

Determination of bio-based content

Some bio-based products can be made 100% bio-based while in others only part of the fossil components are substituted by bio-based components. Bio-based *carbon* content can be measured directly by ^{14}C biogenic carbon determination methods which can be translated to *total* bio-based content if the biological or chemical reaction rules are known. Standardised methods to directly measure both bio-based carbon content and total bio-based content are presented in EN 16785-1:2015. It is also possible to determine the bio-based content indirectly by a material balance approach supplemented by the use of chemical or biological reaction rules to determine the allocation of elements in the final bio-based products. This approach is presented in prEN 16785-2. A detailed assessment of various mass balance and atom connectivity methods, (the latter using chemical reaction rules to determine the bio-based content) can be found in (Clark, Farmer, & Sherwood, 2015).

Carbon content and chain of custody models in biomass certification schemes

Bio-based content methods distinguish between bio-based content and fossil content of a bio-based product. Bio-based content can be made of both sustainable and non-sustainable biomass as represented in Figure 7.

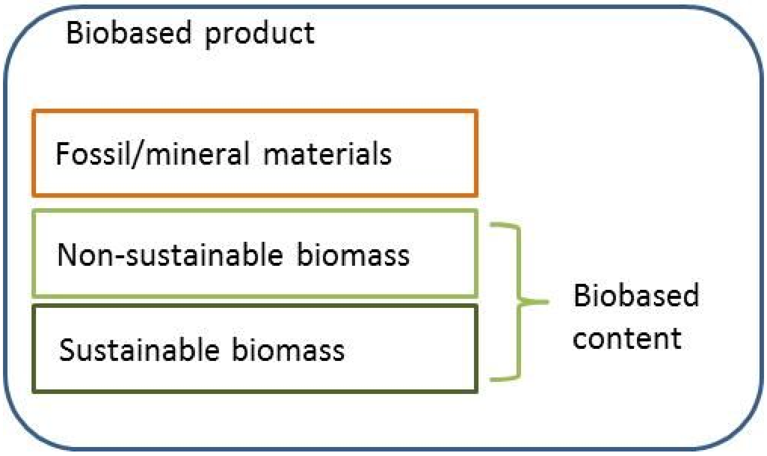

Figure 7: Bio-based content can be produced from both sustainably produced and non-sustainably produced biomass

The chain of custody models in the sustainability schemes are originally designed to certify the sustainability claim. Three main types can be distinguished:

1. Physical segregation: sustainable biomass is kept separate from non-sustainable biomass;
2. Mass balance: sustainable and non-sustainable biomass can be physically mixed and the sustainability claim can be transferred to non-certified biomass/material in the

mixture as long as the total amount of sustainable biomass input equals the total amount of sustainable biomass output;
3. Book and claim allows trade of the sustainability certificates that can be sold to a provider of non-certified biomass, claiming that somewhere an equal amount of certified biomass has been produced.

In case of mass balance and book and claim chain of custody models the sustainability attribute can be transferred, i.e. the end product in hands of the consumer is possibly not physically produced in a certified sustainable way, but it is ensured that a similar quantity has been produced in this way.

A similar approach could be followed for bio-based content. In case of drop-in bio-based products that have chemically exactly the same properties as the fossil product, administrative transfer of bio-based content to a fossil product is in principle possible. The consumer would not notice any difference in the physical product. However, although the attribution of sustainability to a certain fraction of the mixture seems to be well accepted, attribution of bio-based content to a fossil product is often regarded risky and misleading to consumers. Moreover, the transfer of bio-based content to a fossil product would result in biomass or a bio-based product that is declared "non-biogenic", while the bio-based carbon content is still detectable by ^{14}C direct carbon content measurement. This would create for instance bioethanol that is declared fossil, which is a bit odd and has a certain risk of fraud. The requirement of physical presence of bio-based content in the bio-based product has consequences for the applicability of the chain of custody models currently used in biomass sustainability certification schemes. In chapter 8 it is investigated how biomass sustainability schemes that currently allow certification of bio-based products, i.e. NTA8080, RSB and ISCC deal with this issue, and is sought for general recommendations on the application of chain of custody models for bio-based products, in particular for the different variations of the mass balance approach.

Outlook

Biomass certification schemes can be used to certify that the bio-based content of a bio-based product has been produced in a sustainable way, meeting the sustainability criteria of the applied scheme. Both bio-based carbon content and sustainability of the biomass need to be verifiable throughout the supply chain. The applicability of different chains of custody depends on whether the sustainability attribute and the carbon content of the bio-based product should be physically present in the final product. The approach in which bio-based carbon content is always physically available in the bio-based product can be regarded mainstream, and it is probably the most secure way to obtain consumer acceptance. Others, for instance Henke (2014) argue that companies will be stimulated to produce and market bio-based products if they can allocate bio-based content to end products in a less rigid way. For instance, oil refineries that initially can only take in limited amounts of biomass, could profit from a mass balance approach in which the bio-based content claim is allocated to certain products. Only for the last 5 years some biomass sustainability certification schemes (NTA8080, RSB, ISCC) have included certification of bio-based products. Lessons can be learned from the setup of these schemes and practical experience with certification so far, and recent work in CEN TC411 and Open-Bio could help to support the further development of sustainability certification of bio-based products including the use of relevant chain of custody models. It is interesting to mention that NEN recently has launched a certification scheme[10] for certification of bio-based content by radiocarbon analysis and elemental analysis as described in EN 16785-1:2015.

More information on the topic of bio-based content and chain of custody approaches can be found in chapter 8.

3.9 Conclusion

Biomass sustainability themes relevant for bioenergy and biofuels are partly also relevant for bio-based products. In the previous sections it was assessed how bio-based products are positioned compared to bioenergy/biofuels and food/feed regarding different sustainability issues. See also Table 8.

Table 8 Overview of relevant sustainability topics for bio-based products

Sustainability theme	Bio-based products			Bioenergy and biofuels	Covered in biomass certification schemes
Biomass type	Oil bearing	Sugar and starch	Lignocellulosic biomass		
Sustainable production • Environmental • Social • Economic	Y	Y	Y	Y	✓
GHG reduction	Y	Y	Y	Y	✓
Indirect land use change	Y	Y	N	Y	× a)
Carbon debt	N	N	Y	Y	×
Carbon storage	Y	Y	Y	N	×
Cascading of biomass	Y	Y	Y	Y	× b)
Bio-based carbon content	Y	Y	Y	Y	✓

Y= relevant; N= not relevant; ✓= covered in existing sustainability certification schemes; ×= not covered in existing sustainability schemes

a) RSB and NTA8080 offer possibility to show that biomass is low ILUC impact.

b) Better Biomass (NTA8080-1:2015) has a reporting obligation on cascading use.

There is a growing awareness that biomass crops whether produced for food/feed, bio-based products or energy should be produced in a sustainable way. Certification schemes are available to guarantee sustainable biomass production for bioenergy and biofuels and could also be applied to bio-based products and even to food and feed.

Bio-based products are preferable over fossil based products, because they often have environmental benefits. Like bioenergy and biofuels, greenhouse gas emission reduction is

[10] See www.bio-basedcontent.eu

one of these key benefits. The GHG reduction calculation of bio-based products is often far more complex than that of biofuels. Existing sustainability schemes for biofuels and bioenergy do not offer much support here. The EN 16760 standard on Life Cycle Assessment of bio-based products could offer further guidance. Databases with validated LCI data of bio-based products as well as fossil reference products could be established along the lines of existing databases of for instance green building materials.

Indirect land use change could become an important topic for bio-based products using sugar, starch and oil crops especially if the production of bio-based products would expand rapidly, like the production of biofuels did in the recent past. A division could be made between traditional bio-based products that have an established ILUC impact, and new (modern) bio-based products that have an additional land use impact.

The carbon debt discussion is relevant for wood consuming bio-based products, but not for bio-based products using sugar/starch and oil crops. On the contrary, bio-based products with a long lifetime could become carbon pools especially during periods of rapid expansion of its production replacing fossil products.

Cascading of biomass is not a goal in itself but a means to contribute to resource efficiency targets as well as GHG emission reduction. In current preference orders bio-based products are usually placed below food/feed and above energy. However, benefits of cascades including bio-based products need to be compared to reference alternatives, in order to appreciate the benefits of the bio-based products properly.

Bio-based products are often only partly biogenic. Methods to determine bio-based content might interfere with chain of custody approaches currently used to trace the sustainability attribute of biomass. Approaches will depend on whether the sustainability of the biomass physically available in the bio-based product is to be certified or whether claims on the use of biomass in the production process but not necessarily in the product itself is sought after.

4 Life cycle analysis of bio-based products and evaluation of GHG emission reduction

4.1 Introduction

In Section 3 we discussed the main sustainability issues regarding bio-based products and the current development of standards and sustainability certifications. We concluded that existing sustainability schemes cover sustainable biomass production well, while other aspects such as indirect land use change (ILUC), carbon debt, carbon storage, and cascading of biomass are not or only partly represented. Greenhouse gas (GHG) emissions of bio-based products are addressed by all schemes compared in this study (Draft NTA8080-2:2014, RSB, ISCC), but the calculation of emissions is optional in two of three schemes and no reduction of GHG emissions is required for certification under any of the three schemes, as presented in Table 7.

The results of Open-Bio WP 9 show that sustainability of bio-based products is one of the main concerns of (potential) consumers (Sijtsema et al., 2015). They are concerned about feedstock origin and sustainable biomass production, which is covered well in current schemes. The assessment furthermore shows that governmental organizations and NGO's consider the reduction of GHG emissions as very important aspects.

The potential to reduce GHG emissions is one of the main drivers of the transition towards a bio-economy in Europe. While this is an important factor stimulating the production of bio-energy, the development of bio-based products strives for additional goals, such as replacing fossil-based products or creating innovative products with new functionalities. Whether or not bio-based products reduce GHG emissions in comparison to their fossil-based benchmarks, however, is one of the main factors determining whether bio-based products are indeed sustainable and find social acceptance. Determining GHG emissions is thus of great importance for determining the sustainability of bio-based products.

In this chapter, we discuss the determination of GHG emission reduction of bio-based products and the potential to include this in sustainability schemes. We focus on Life cycle analysis (LCA), a well-known tool to determine the environmental impact of a given product. The methodology was known under different names, e.g. ecobalances, before it was first called LCA in 1991 (Baumann & Tillmann, 2004). It is based on the concept that any stage during the production, use and disposal phase of a product may have an impact on the environment, e.g. in the form of GHG emissions. Therefore, the life cycle of a product is analysed, preferably from "cradle to grave" or "cradle to cradle", thus including all resources serving as input and all intermediate and final outputs. Figure 8 schematically shows a life cycle model. Since 1997, the ISO standard series 14040 concerned with the methodology of conducting an LCA has been developed. ISO 14040 depicts the required stages of an LCA, as shown in Figure 9, and further defines how LCAs have to be conducted.

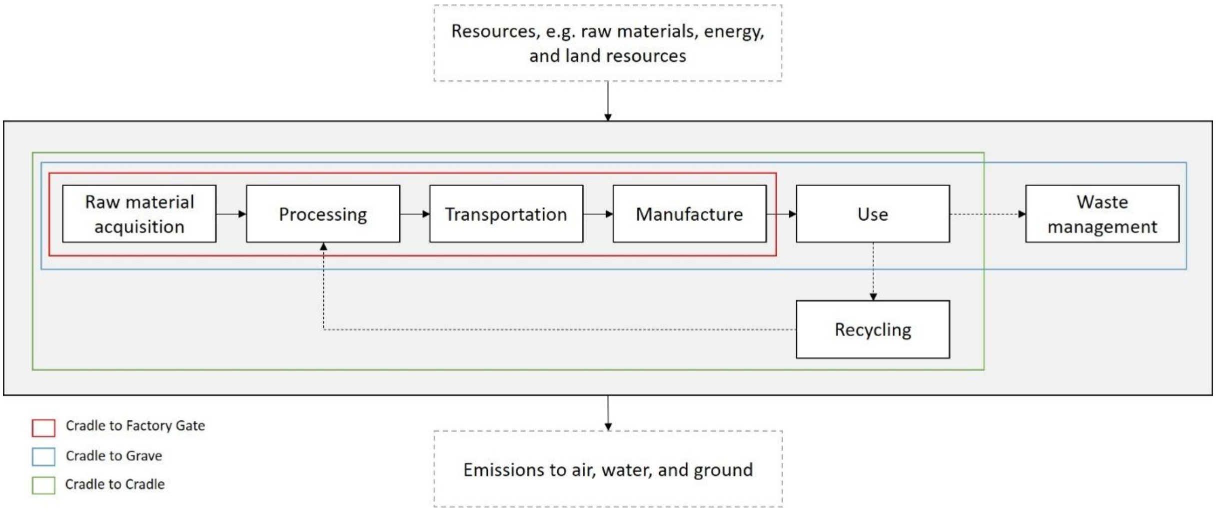

Figure 8: Life cycle model including different analysis scopes (extended from Figure 1.1 in Baumann & Tillmann, 2004)

In this chapter we present the results of a literature review of LCA studies of bio-based products. The goal of this review was to analyse the current practice of LCAs of bio-based products, to gain an overview about the methodological state of the art, and to discover how the sustainability issues raised in Section 3 are addressed. In this chapter, we focus on aspects related to GHG emission reductions, since this is not covered in depth by current sustainability schemes.

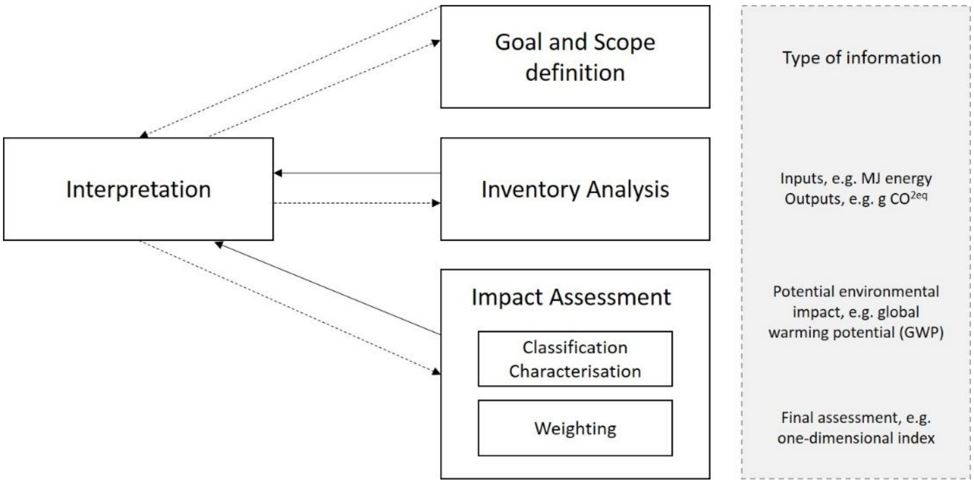

Figure 9: LCA procedure (adapted from Baumann & Tillmann, 2004)

4.2 Methodology

We selected literature using the search query "LCA bio based material" in the topic field on Web of Science. The search was conducted on 13 August 2015 and at that time revealed 58 results. Of these results we selected all empirical studies reporting results of LCAs of bio-based material production, including both intermediate and consumer products. This selection process yielded 22 studies, which are listed in the results in Table 9. To analyse the literature, we developed a framework based on general LCA methodology literature and earlier articles discussing LCA methodology of bio-based products, namely: Pawelzik et al., 2013 and Weiss et al., 2012. Pawelzik et al. (Pawelzik, Carus, Hotchkiss, Narayan, Selke, Wellisch, Weiss, et al., 2013) discuss critical aspects of LCA methodology regarding bio-based products; Weiss et al. (2012) present a meta-analysis of the results of bio-based product LCAs. Among them, the two articles identify 12 aspects important to consider: (primary) Energy use, GHG emissions, Eutrophication, Acidification, Stratospheric ozone depletion, Tropospheric / Photochemical ozone formation, Consideration of LUC and ILUC impacts, Consideration of land use efficiency, Consideration of residue utilisation, Consideration of carbon storage, and Consideration of End-of-Life. We analysed these aspects together with some additional ones identified in general LCA literature, which amounted to 24 aspects in total. In this chapter we will, however, exclusively focus on seven aspects that are related to GHG emission reductions.

4.3 Results

Table 9 shows the results of the literature analysis described above, including the references of the reviewed literature and the product groups of the addressed materials and products. The biggest product groups are packaging materials, construction materials and polymers. All except one study compare the environmental impact of a bio-based product with that of their respective fossil benchmark. For example, the impact of a bio-based packaging film in comparison with the impact of a fossil-based packaging film with the same functional characteristics (the same "functional unit"). Most papers considered the whole life cycle by choosing a Cradle to Grave (14) or Cradle to Cradle (2) analysis scope (cf. Figure 8), with one or more End-of-Life scenario's. In six papers the analysis was limited to Cradle to Factory Gate. The primary reason for this decision named was missing data or great variability (and thus uncertainty) during the use phase. Energy use, GHG emissions, ILUC impacts and Carbon Storage are directly or indirectly linked to GHG emissions during the life cycle.

Table 9: Overview of LCA studies included in the review and their coverage of GHG-related aspects

Reference	Product group	Compara-tive	Scope*	End-of-Life	Energy use***	GHG emissions	ILUC impacts	Carbon Storage
Bos et al. (Bos, Meesters, Conijn, Corré, & Patel, 2012)	Polymers	Yes	CFG	No	NREU	Yes, different paper	Recommended for future research	Yes, considered as stored (referring to Lead Market Initiative, 2009)
Deng et al. (Deng, Achten, Van Acker, & Duflou, 2013)	Bioplastic / packaging	Yes	CGR	Yes, bio-degradable	NREU	Yes	No	Yes, considered as non-consequential in the CGR perspective
Duflou et al. (Duflou, Deng, Van Acker, & Dewulf, 2012)	Construction material	Yes	CGR	Yes	CED	Yes	No	No
Duflou et al. (Duflou, Yelin, Van Acker, & Dewulf, 2014)	Construction material	Yes	CGR	Yes, incineration + CHP	No	Yes	No	No
Ganne-Chedeville and Diederichts (Ganne-Chedeville & Diederichs, 2015)	Construction material	Yes	CGR	Yes, energy recovery, combustion in municipal incineration plant	No	Yes	Yes, based on results Searchinger et al. (2008) and Wicke et al. (2012)	No
Gonzáles-García et al. (González-García, Feijoo, Heathcote, Kandelbauer, & Moreira, 2011)	Construction material	Yes	CFG	No	CED	Yes	No	No
Hermann et al. (Hermann, Blok, & Patel, 2010)	Packaging material	Yes	CFG and CGR	Yes, incineration (with and without energy recovery), landfilling, composting, and digestion	NREU	Yes	No	No
Khoo et al. (Khoo, Tan, & Chng, 2010; Khoo & Tan, 2010)	Packaging material	Yes	CGR	Yes, land filling, incineration, composting	No	Yes	No	No
Kimura et al. (Kimura & Horikoshi, 2005)	Polymer	Yes	CGR	Yes	FFU **	Yes	No	No
Koller et al. (Koller, Sandholzer, Salerno, Braunegg, &	Polymer	Yes	CFG **	No, Considered the same as fossil benchmark	CED **	No	No	No

Reference	Product group	Compara-tive	Scope*	End-of-Life	Energy use***	GHG emissions	ILUC impacts	Carbon Storage
Narodoslawsky, 2013)								
La Rosa et al. (a. D. La Rosa et al., 2013)	Construction material	Yes	CGR	Yes, landfilling	CED	Yes	No	No
La Rosa et al. (a. D. La Rosa et al., 2014)	Construction material	Yes	CFG **	No	CED	Yes	No	No
La Rosa et al. (A. D. La Rosa et al., 2014)	Construction material	Yes	CFG	No	CED	Yes	No	No
Leceta et al. (Leceta, Etxabide, Cabezudo, De La Caba, & Guerrero, 2014)	Packaging material	Yes	CGR	Yes, composting	FFU	Yes	No	No
LeCorre et al. (LeCorre, Hohenthal, Dufresne, & Bras, 2013)	Polymer	Yes	CGR **	Yes, biodegradable share compared	GER	Yes	No	No
Madival et al. (Madival, Auras, Singh, & Narayan, 2009)	Packaging material	Yes	CC	Yes, incineration, landfill, recycling, composting	NREU	Yes	No	No
Mirabella et al. (Mirabella, Castellani, & Sala, 2013)	Bioplastic / hygiene product	Yes	CC + EoL	Yes, composting, landfilling, incineration	CED	Yes	No	No
Pretot et al. (Pretot, Collet, & Garnier, 2014)	Construction material	Yes	CGR	Partly	PED	Yes	No	Yes, carbon sequestration based on carbonation of the binder assumed
Razza et al. (Razza et al., 2015)	Packaging material	Yes	CGR	Yes, composting, incineration, recycling, landfill depending on component	NREU	Yes	No	No
Renouf et al. (Renouf, Pagan, & Wegener, 2013)	Polymer	No	CGR	Yes, degradation of PLA considered, plus capture of methane for energy production	NREU	Yes	No	No
Suwanmanee et al. (Suwanmanee et al., 2013)	Packaging material	Yes	CFG	No	No	Yes	Yes, based on results Piemonte and Gironi (2011)	No

Reference	Product group	Compara-tive	Scope*	End-of-Life	Energy use***	GHG emissions	ILUC impacts	Carbon Storage
Wang et al. (Wang et al., 2010)	Packaging material	Yes	CGR	Yes: landfilling (with energy recovery), home composting, anaerobic digestion (with energy recovery), incineration (with energy recovery) and recycling	No	Yes	No	Yes, assume advantage in GWP through sequestration of CO_2 into the product

* Cradle to Factory Gate (CFG), Cradle to Grave (CGR), Cradle to Cradle (CC), End-of-Life options (EoL).
** not specifically stated
*** Non-Renewable Energy Use (NREU), Cumulative Energy Demand (CED), Fossil Fuel Use (FFU), Gross Energy Required (GER), Primary Energy Demand (PED)

Energy use is addressed by 18 articles, of which most quantify the impact of either the cumulative energy demand (CED) or the non-renewable energy use (NREU). It stands out that all articles consider GHG emissions. Two main impact categories for GHG emissions can be distinguished: 12 articles calculate and compare the global warming potential (GWP) in CO_{2eq} as indicator, seven express emissions as a climate change impact factor, mostly as part of an established life cycle impact assessment (LCIA) method, such as ReCiPe. The chosen LCIA methodology largely determines how GHG emissions are regarded: methods such as ReCiPe determine a climate change impact factor at the midpoint level and translate it (optionally) into an endpoint impact such as the impact on human health. Others, such as the IPCC method aim more directly at expressing results in GHG emissions or GWP.

ILUC impacts are considered by only two articles. They base their calculations on formerly published results, which they apply for their specific cases (Ganne-Chedeville & Diederichs, 2015; Suwanmanee et al., 2013). Only one article explains why they do not consider ILUC impacts: Bos et al. (2012) argue that there is an ongoing dispute about suitable ways of accounting for (I)LUC effects, without consensus on adequately addressing these issues. Since ILUC can have a large impact on the results, they recommend addressing this in future research. Ganne-Chedeville and Diederichs (2015) and Suwanmanee et al. (2013) base their calculations on former studies and thus seem to overcome this problem. However, the cited studies present or summarise numbers that are very specific for certain situations and the respective authors caution readers for great uncertainty in the results, due to the young field of research and lacking data (Piemonte & Gironi, 2011; Wicke et al., 2012a).

Four articles consider **carbon storage in the bio-based products**. Deng et al. (2013) argue that accounting for CO_2 sequestration does not influence the overall outcome on a cradle-to-grave perspective. They analyse a bio-based packaging film that is bio-degradable and assume CO_2 uptake by the biomass at the beginning and biogenic CO_2 emissions at the end of the life cycle to be the same. Bos et al. (2012), Pretot et al. (2014), and Wang et al. (2010) assume carbon to be stored in the product. It stands out that Bos et al. (2012) chose a cradle-to-factory gate life cycle (suiting their research goal) and thus conclude their analysis at the stage of a manufactured product, which indeed contains all carbon taken up by the biomass. Pretot et al. (2014) and Wang et al. (2010), however, use a cradle-to-grave life cycle and still conclude that carbon storage offers advantages. Pretot et al. (2014) argue, that carbon is sequestered in the assessed building material (concrete walls containing hemp) through the photosynthetic take up of CO_2 by hemp and subsequent storage in the product for an estimated lifespan of 30-100 years. Furthermore, they assume a carbonation effect of the lime-based binder, further sequestering CO_2 throughout the lifespan. Wang et al. (2010) argue that an advantage in GWP is achieved through the sequestration of CO_2 in the assessed packaging material (wheat-based foam for insulating boxes). They argue that long-term carbon storage is achieved in the case of landfilling as end-of-life scenario. A more detailed review on the role of carbon storage in bio-based products as means to mitigate climate change is presented in chapter 6.

4.4 Discussion

One of the most important drivers behind the switch to a bio-economy is the reduction of GHG emissions, but this is only partly covered by current sustainability schemes for bio-based products. We reviewed the current practice of LCAs of bio-based products, focussing on the consideration of factors influencing the overall GHG emissions, and will now discuss the potential to include the determination of GHG emissions in sustainability schemes.

Empirical LCAs of bio-based products have been published since 2010 and mostly aim at comparing a bio-based product with its fossil benchmark. In contrast to the direct calculation of GHG emissions, factors influencing these emissions are considered to highly varying degree. Diverging energy use indicators are applied (e.g. considering all energy sources *vs.* only non-renewable energy), and ILUC and carbon storage are addressed only sporadically. This shows that while GHG emissions are considered important, influencing factors are generally not taken into account in current bio-based product LCA practice. Methodological difficulties described are lack of data and lack of consensus on appropriate methodology.

European Standard for lifecycle assessment of bio-based products

The newly developed European Standard EN 16760 "*provides guidance and requirements to assess impact over the life cycle of bio-based products*". The standard states that GHG emissions and removals from both fossil and biogenic carbon sources and sinks must be listed in the inventory analysis and should be considered in the impact assessment. It provides descriptions of typical emissions in bio-based product life cycles, such as CO_2 and CH_4 emissions from soil, and recommends guidelines to calculate these emissions (e.g. other EN standards and IPCC guidelines). Later, it introduces two approaches for modelling CO_2 emissions related to biogenic carbon, either including CO_2 sequestration in biomass with negative values and emissions at the end-of-life with positive values, or appointing both a factor zero. Section 5.4.2.2.5 of EN 16760 refers to the consideration of land use change in GHG accounting and states that for ILUC there is currently no agreed scientific method in coherence with the modelling principles of LCA, and that it may only be addressed in the interpretation phase. In comparison to the methods applied in the LCAs reviewed here, this standard provides more specific recommendations regarding GHG emission consideration. However, it confirms our finding that there is not yet a consensus on how to include ILUC in GHG emission calculations. Furthermore, methods for accounting for carbon storage are not addressed in the standard itself but only described in Annex B, where it is mentioned that temporal accounting for carbon storage may be included based on guidance from the International Life Cycle Data (ILCD) Handbook.

ILUC and Carbon storage in LCAs

Pawelzik et al. (2013) discuss seven methods to account for carbon storage in LCAs and recommend accounting for it, depending on the life cycles of the products and the expected duration of carbon storage. Our analysis showed that up till now carbon storage is seldom considered in LCAs of bio-based products and then based on different assumptions. Following ISO 14067 carbon storage can be recorded for products with lifespans of more than 10 years, but outside of the LCA itself. The impact of the radiative force of carbon released sooner or later into the atmosphere is extremely complex, depends on many factors, and is insufficiently understood to allow for accurate integration in an LCA. Therefore, the inclusion in the LCA bears a significant risk of falsifying overall results.

Overall GHG emissions are an important sustainability indicator for bio-based products, but to address them more precisely in LCAs, more research is required. Aspects such as ILUC and carbon storage are currently rarely considered and there is no scientific consensus on appropriate methodologies. The new EN 16760 Standard gives more specific guidance on GHG calculations in LCAs of bio-based products, but does not solve all methodological problems. As described in Section 3, GHG emission reductions are not required by current sustainability schemes, though stakeholders and consumers deem them very relevant. Even though aspects like ILUC and carbon storage cannot yet be considered thoroughly, the review of LCAs showed that it is current practice to calculate and compare GHG emissions, and that there are well established impact assessments that address the emissions. This could provide a good start for the inclusion of GHG emissions in sustainability schemes for bio-based products. It would, however, be a high toll to ask of producers to conduct full LCAs to comply with sustainability schemes, since LCAs are time consuming and expensive.

Suggestions on GHG emission calculations of bio-based products

In the outlook in Section 3.2 we concluded: “This trend towards sustainability requirements for all land-based biomass sources could eventually lead to movement from (time and effort consuming) specific sustainability certification schemes toward general applicable legislation covering sustainability topics comprehensively.” Maybe such a more general evaluation of sustainability could in the future be accompanied by a GHG balance. For example by supplying a CO_{2eq} value for a large variety of biomass types up to the point in the life cycle where it is distributed and applied for various products. The data would have to be specific regarding important aspects (time, location, origin, weight, volume, dry weight etc.). Specific entries could, for example, be related to what is sold on the market by biomass intermediaries. Biomass owners or intermediaries could then get a sustainability certificate that comprises different issues of sustainable production (similar to PEFC etc.) plus the GHG balance up to the point of selling biomass in a certain market. The balance would have to represent both carbon emissions (expressed in positive values) and savings or sequestration (expressed in negative values). A complete evaluation of GHG emissions cannot be conducted at that point, because the further processing, use, and end-of-life is unknown. To determine GHG savings in comparison to fossil-based products, the fossil benchmark has to be known. It is often very difficult for stakeholders in the bio-based industry to evaluate GHG emissions (or impact in general) of feedstocks, because the origin and details about the life cycle of the biomass up to that point are unknown. A new or improved sustainability scheme, comprising different sustainability aspects and including a GHG balance up to the point of feedstock provision, would make an analysis of overall GHG emissions much easier and less time consuming. Bio-based producers could calculate the GHG balance starting with the number provided with the feedstock and include their processing, use, and end-of-life phase (either or not in comparison with a specific fossil benchmark).

Finally, in some situations it may be desirable to not only include a GHG balance in the sustainability evaluation of bio-based products, but conduct a full LCA, including other environmental impacts. This process could be improved by including entries for various biomass types in LCA databases, such as ecoinvent, up to the point of sales by intermediaries as input for further processing. This way, all data relevant for full LCAs could be supplied in a relatively approachable way. These data would be much more extensive, but also more inclusive where deemed useful.

4.5 Conclusion

Empirical LCAs of bio-based products mostly aim at comparing bio-based products with their fossil benchmark. GHG emissions are assessed in all reviewed articles, but indirect factors influencing these emissions are considered to highly varying degree. Diverging energy use indicators are applied (e.g. considering all energy sources *vs.* only non-renewable energy), and ILUC and carbon storage are addressed only sporadically. The newly developed European Standard EN 16760 introduces two approaches for modelling CO_2 emissions related to biogenic carbon, either including CO_2 sequestration in biomass with negative values and emissions at the end-of-life with positive values, or appointing both a factor zero. In comparison with the guidance described in the European RED and the methods applied in the LCAs reviewed here, this standard provides more specific recommendations regarding GHG emission consideration. However, it confirms our finding that there is not yet a consensus on how to include ILUC in GHG emission calculations. Overall GHG emissions are an important sustainability indicator for bio-based products, but to address them more precisely in LCAs, more research is required. Aspects such as ILUC and carbon storage are currently rarely considered and there is no scientific consensus on appropriate methodologies. The new EN 16760 Standard gives some guidance on GHG calculations in LCAs of bio-based products, mainly directing readers to other sources, such as the IPCC, RED or ISO standards, but does not solve all methodological problems. As described in Section 3, GHG emission reductions are not required by current sustainability schemes, though stakeholders and consumers deem them very relevant. Even though aspects like ILUC and carbon storage cannot yet be considered thoroughly, the review of LCAs showed that it is current practice to calculate and compare GHG emissions, and that there are well established impact assessments that address the emissions. This could provide a good start for the inclusion of GHG emissions in sustainability schemes for bio-based products.

5 Indirect land use change

5.1 Introduction

When pasture or agricultural land previously destined for food, feed and fibre production is diverted to biofuel/bioenergy/bio-based products production, the existing demand will need to be satisfied either through intensification of the current production or by bringing non-agricultural land into production elsewhere. The latter case represents indirect land-use change (ILUC) and could potentially lead to significant greenhouse emissions, if it involves the conversion of high carbon stock land.

Since the publication of the ILUC proposal (COM(2012)595) by the European Commission, the discussion on ILUC and the possibilities to introduce ILUC factors that translate the ILUC emission impact to the level of an economic operator has been intensified. The proposal contains specific ILUC factors for cereals and other starch rich crops, sugars and oil crops. Especially the ILUC factor of oil crops of (55 gCO_{2eq}/MJ) would have shrunk the reduction of greenhouse gas emissions achieved by biodiesel below the threshold of 35% emission reduction, directly threatening the biodiesel industry. The finally approved ILUC Directive (2015/1513) contains a reporting obligation for Member States and the Commission, however, individual biofuel producers do not have to take into account ILUC factors in their GHG reduction calculations.

This chapter briefly discusses the status of ILUC research, the (im)possibilities of the introduction of ILUC factors in biomass sustainability schemes, and its relevance for bio-based products.

5.2 Review of ILUC research

Searchinger et al. (2008) were the first to estimate indirect land use change emissions related to the US biofuel consumption by means of a modelling framework. They looked at different alternative feedstocks used to produce ethanol using the FAPRI-CARD model. Since then, the estimation of ILUC GHG emissions has received considerable attention with a particular focus on first generation biofuels, i.e. those produced from food and feed crops.

Recently the results of the Globiom study (Valin et al., 2015), called after IIASA's Global Biosphere Management Model (GLOBIOM), commissioned by the European Commission were made public. This study is briefly discussed as example of a relevant ILUC study, with focus on the ILUC impacts of biofuels produced to meet the EU biofuel targets, which may play an important role in the discussion on the future biofuel policies of the European Commission after 2020. The Globiom study follows the general principles of ILUC modelling used in earlier studies, in which a “world with additional biofuels” (the policy scenario) is compared to the same world “as it would have developed without the additional biofuels” (the baseline). Because ILUC occurs through global market mechanisms with many direct and indirect effects, it can only be modelled, not measured. Direct measurement will only provide partial accounting of the total effects.

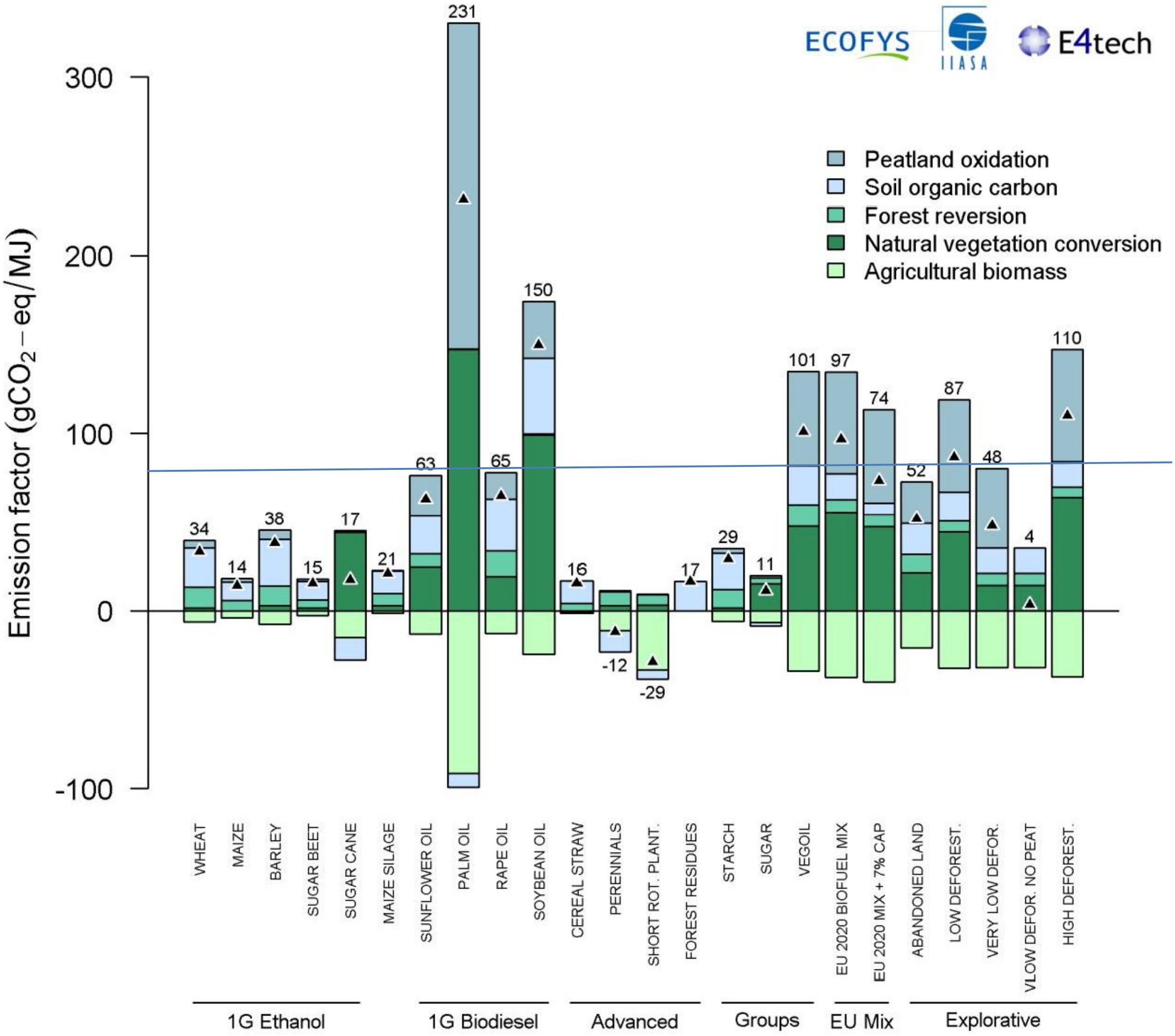

Figure 10: Overview of GLOBIOM modelling results: LUC emissions per scenario. Source: (Valin et al., 2015)

The results of the study, commonly referred to as “ILUC values” (or “factors”), are in fact the sum of direct and indirect emission effects. The modelling does not show to what extent the land conversion is caused directly or indirectly. For this reason, the study speaks about “LUC values” rather than “ILUC values” and about “land use change” rather than “direct or indirect land use change”. Figure 10 shows the main emission factors as found in the GLOBIOM study. The emission factor of fossil diesel and petrol are in the order of 83.8 gCO_{2eq}/MJ (2009/28/EC, 2009,Annex V, art 19), showing that in quite some cases the greenhouse emissions of land use change exceed the emissions of fossil fuels. Especially palm oil and soy bean oil have negative greenhouse emission impacts.

Drainage of peatlands in Indonesia and Malaysia plays a large role in LUC emissions for vegetable oils. This is especially the case for palm oil: 69% of gross LUC emissions for palm oil is caused by such peatland oxidation after land conversion. One of the major contributors to LUC emissions, peat land drainage, is a relatively local problem. If peatland drainage in Indonesia and Malaysia were stopped, the negative greenhouse gas impact of land use change would reduce dramatically (Valin et al., 2015).

The Globiom study is one of many studies published since Searchinger (2008). See for instance review studies such as (Gallagher, 2008), (Edwards, Mulligan, & Marelli, 2010), (Marshall et al., 2011), (Plevin, Beckman, Golub, Witcover, & O'Hare, 2015), (Overmars, Stehfest, Ros, & Prins, 2011), (Wicke, Verweij, van Meijl, van Vuuren, & Faaij, 2012b), (Malins, Searle, & Baral, 2014) The review studies compare the resulting LUC factors and underlying models and assumptions. In general, modelling LUC requires a large amount of parameters of which many are uncertain and poorly supported by empirical evidence. For instance, underlying data to determine yield responses and elasticities[11] are often of low quality and poorly described. They tend to be based on historical data, implying that future projections extrapolate what happened in the past. Elasticities are often not specified per crop and region although these differences exist. For instance the price yield elasticity (the relative increase in yields for a given increase in prices) is 0.32 in the GTAB model used for CARB, and 0.25 in a later GTAP model runs, while EPA used a value of 0.013 for the short term and 0.074 for the long term (Wicke et al., 2012b). Many other examples of uncertainties and shortcomings in ILUC modelling could be presented, please refer to the above mentioned review studies for more information.

5.3 Strategies to avoid ILUC

Given the information available provided by models and their shortcomings, the question rises what strategies could be followed to mitigate ILUC. A main strategy for minimizing ILUC is the promotion of biofuels produced from biomass with low ILUC risks, such as currently unused residues from agricultural crops and forestry production and processing as well as woody and grassy feedstocks for second-generation biofuels production, particularly those produced on degraded and marginal land. Residues and by-products that are not currently used, and that can therefore be classified as 'waste', will cause little to no ILUC. However, if currently used residues are diverted to bioenergy or bio-based products, they are likely to have negative impacts (including ILUC) (Wicke et al., 2012b).

RSB and NTA8080 promote low ILUC biomass through the use of a "Low Indirect Impact Biofuels" (LIIB) approach that has been developed by WWF, Ecofys and EPFL (van de Staaij et al., 2012). The LIIB approach allows four types of projects that could be regarded as low ILUC:

1. Biofuels from waste. Projects that use residues or waste streams that are listed on the scheme owners' positive list of feedstock with a low risk of unwanted indirect impacts.

[11] Like Elasticity of food demand to price, yield to price, area to price. See (Malins et al., 2014)

2. Feedstock production from increased yields. Projects should show an average yield increase of at least 20% compared to the baseline within a certain period;
3. Feedstock production from unused land. Projects that cultivate biofuels on land that has not been used for its provisioning services in the last three years, located in a region with an excess potential of unused arable land.
4. Feedstock production from integrated sugarcane and cattle or other biofuel feedstock integration projects (for which a methodology needs to be developed)[12].

It can be anticipated that “biofuels from waste” is the most common category for which the methodology is simply to compare the used biomass type with a list of accepted feedstock. Probably feedstock production from unused land would be the second most relevant product type. See (RSB, 2015a) for a further elaborated LIIB methodology that is part of the RSB scheme since April 2015. So far no projects were identified that carry the low ILUC risk claim. The methodologies for the identification and certification of Low ILUC risk biofuels are currently developed further by (Hamelinck & Toop, 2016).

Besides the use of low ILUC feedstock specifically for biofuels, strategies to avoid ILUC are generally beyond the scope of biomass sustainability certification, and address agricultural production in general. Examples of such strategies are (Wicke et al., 2012b):

- Increase efficiencies in agricultural crop and livestock production;
- Integrate food, feed and fuel production to increase total biomass production per hectare;
- Improve efficiencies of agricultural, forestry and bioenergy supply chains;
- Minimize degradation and abandonment of agricultural land;
- Apply other forms of highly efficient land use like growing algae.

In addition to minimizing the extent of LUC, the impacts of LUC can be minimized by controlling the type of LUC. The main strategies are to (Wicke et al., 2012b):

- Develop and implement sustainable land use planning and monitoring;
- Exclude high carbon stock and important biodiversity areas by land use policies all around the world; for example, if peatland drainage in Indonesia and Malaysia were stopped, the negative greenhouse gas impact of land use change would reduce dramatically. This requires an effort either from the Indonesian and Malaysian governments, all palm oil using sectors (food, personal care products, biofuel) or, best of all, a combination of both (Valin et al., 2015);
- Promote the use of marginal land, degraded lands or abandoned agricultural land for bioenergy and material production.

[12] Ecofys recently proposed a methodology for intercropping as a way to increase the yield of land. See (Hamelinck & Toop, 2016)

5.4 Conclusion

Although RSB and NTA8080 have implemented a low ILUC risk methodology, none of the existing biomass sustainability certification schemes have implemented ILUC factors for agricultural biomass to compensate for indirect emissions elsewhere, as was proposed in EC proposal COM(2012)595 for the “ILUC Directive”. RSB and NTA8080 stress the importance of this matter in their documentation, but see no possibilities to address this properly on farm level. Although ILUC modelling is still a relatively young field of expertise and can be further optimised, it will be very difficult to develop ILUC factors that take into account greenhouse gas emissions related to ILUC of different crops that have a high reliability at farm level. However, models like GLOBIOM can show which biomass feedstock have higher and lower ILUC risks. It would be good practice for producers of bio-based products to avoid high ILUC risk feedstock.

6 Carbon storage in bio-based products

6.1 Introduction

Whether or not to give a value to temporary carbon storage is a hotly debated issue among the environmental assessment community (Levasseur et al., 2011). Temporary carbon storage is, by definition, reversible. On the long term most carbon stored in products will eventually be released, however, it can be beneficial to store carbon on a short term (within the next 100 years) buying time to further develop a low carbon economy. A number of approaches to include temporary carbon storage at product level in LCA are described in (Pawelzik, Carus, Hotchkiss, Narayan, Selke, Wellisch, & Weiss, 2013)[13] and briefly discussed in section 4.4.

In this chapter, another approach is explored, by evaluating the additional temporary carbon storage contribution of the product in the context of the development of the carbon pool of the product at macro scale. As already illustrated in section 3.6, the impact of carbon storage in bio-based products on macro scale can be estimated by using the IPCC HWP model if information is available on the average lifetime of the bio-based product, historical production volumes, and the bio-based carbon content of these products. If this information is available at EU28 level, it could be used in sustainability schemes to assess the carbon storage impact on the level of an individual product as well.

Carbon storage in bio-based products is temporary. At the level of an individual bio-based product the carbon stored in the product could be expressed as the bio-based carbon content times the weight of the product. However, the net contribution of a certain bio-based product to carbon storage on macro level depends on whether this product replaces an existing bio-based product or not. If the bio-based product is completely new and replaces a fossil based product, the carbon content of the bio-based product contributes to additional carbon storage for 100%. If the production volumes are stable for many years and the production of new bio-based products is in equilibrium with the disposal of these products, the additional carbon storage eventually becomes zero. This principle can be expressed by introducing an “Additional Carbon Storage Factor” (ACSF), which is 1 if a product is new in the market and equals 0 in a saturated market. Actually, if the production volume would decrease, the carbon pool will eventually decline, resulting in a negative ACSF. The ACSF can be estimated with help of the IPCC HWP model (tier 2). If generic ACSF factors of various bio-based products could be calculated at EU28 level, they could be used by

[13] The ILCD handbook for instance distinguishes between carbon that is released within a 100 year time period and carbon that is released more than 100 years after the bio-based product was produced. The temporary carbon storage impact is calculated by multiplying the mass of carbon by the lifetime of the product and divide it by 100 years (Pawelzik, Carus, Hotchkiss, Narayan, Selke, Wellisch, & Weiss, 2013).

sustainability schemes to estimate the carbon storage impact of an individual product[14] and take it into account in their GHG emission reduction calculation.

In this chapter this concept is further explored. In section 6.2 the IPCC HWP model is further explained and in section 6.3 the model is applied to determine the Additional Carbon Storage Factor (ACSF) of main semi-finished wood products such as sawn wood and panels. Wood is the most applied (traditional) bio-based product for which relatively good production statistics are available. Moreover, it has a relatively long lifetime. Therefore, wood is suitable for illustrating how the IPCC HWP method can be used to determine the Additional Carbon Storage Factor. In section 6.4 a first order estimation of the possible carbon storage impacts of a number of innovative bio-based products is made to evaluate if carbon storage in innovative bio-based products is significant. In section 6.5, the possibilities to incorporate carbon storage in sustainability certification systems are further evaluated.

6.2 Modelling carbon storage with the IPCC HWP model

One of the benefits of bio-based products is that carbon sequestered during the growing phase of the biomass, remains stored during the lifetime of the product. Several methods have been developed to calculate the amounts of carbon stored in harvested wood products (HWP) (see for instance Brandão et al. (2013)). The (IPCC, 2006) has developed a method for calculating HWP in national greenhouse gas inventories. The European Commission has decided (Decision 529/2013/EU) to introduce obligatory monitoring of harvested wood products based on the same method. The IPCC method has been updated in 2013 (IPCC, 2013).

The carbon stock change of this first order decay model is mathematically described in the following way:

$$C(i+1) = e^{-k} * C(i) + \left[\left(\frac{1-e^{-k}}{k}\right)\right] * Inflow(i)$$

C(i) = carbon stock in year i in tonnes carbon
C(i+1) - C(i) = carbon stock change in year i in tonnes carbon
inflow (i) the inflow in Gg C in year i
k = decay constant (k = ln(2)/half life)

One important variable is the half-life of a wooden product. The EU decision 529/2013/EU provides the following default-half life values[15]:

- 2 years for paper
- 25 years for wood panels
- 35 years for sawn wood.

[14] In a similar way, the average emission factor of electricity produced in the EU28 is published by JRC (Giuntoli et al., 2015).
[15] It means that the assumed average **total** lifetime of the products is 3 years for paper, 36 years for wood panels and 50 years for sawn wood. (half life = average lifetime x ln(2)

To illustrate this model, an example is provided of wooden products with an average lifetime of 10 years. Figure 11 shows the average carbon stock of a bio-based product containing 10 kg of carbon[16] produced in the year 2015. The half-life of the product is approximately 7 years, meaning that in 2022 half of the products still exists. There is a certain probability that the product will have a life longer than 10 years, as shown by the dots after 2025. Note that if an individual bio-based product would be monitored, the curve would stay horizontal at 10 kg carbon stored, until the end of its life, after which the carbon stock would drop to zero. On macro level, the proposed method represents reality better, as it works with an average lifetime of the wooden product, which varies between individual products.

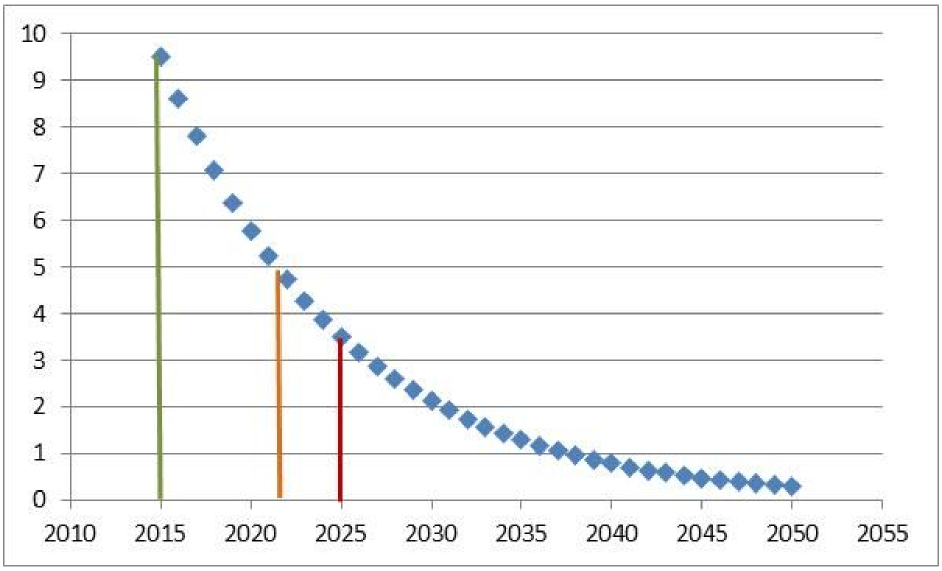

Figure 11: Average carbon storage of a product containing 10 kg of carbon produced in 2015 with an average lifetime of 10 years

Figure 12 shows the development of the carbon stock within the wood products sector if each year a wooden product containing 10 kg of carbon is produced. It shows that the carbon stock increases fast in the first years, and that the growth of the stock declines, because after some time not only new products are added to the stock but also old products are removed as they reach their end of life. After a certain period, in this case about 40 years, an equilibrium is reached resulting in a total carbon stock of nearly 100 kg of carbon.

[16] This equals approximately 20 kg wood or other lignocellulosic biomass.

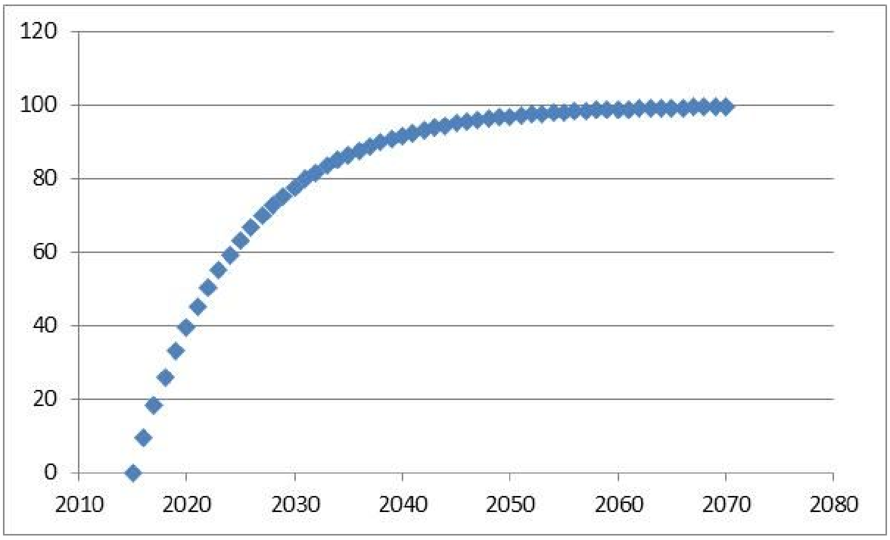

Figure 12: Development of the carbon stock if each year a product of 10 kg carbon with an average lifetime of 10 years is produced, starting in 2015.

Figure 13 shows the development of the carbon stock if the production of the product stops after 20 years in 2035. It illustrates the temporary character of the carbon stock. The stock will decline quickly if the new supply of wooden product is halted.

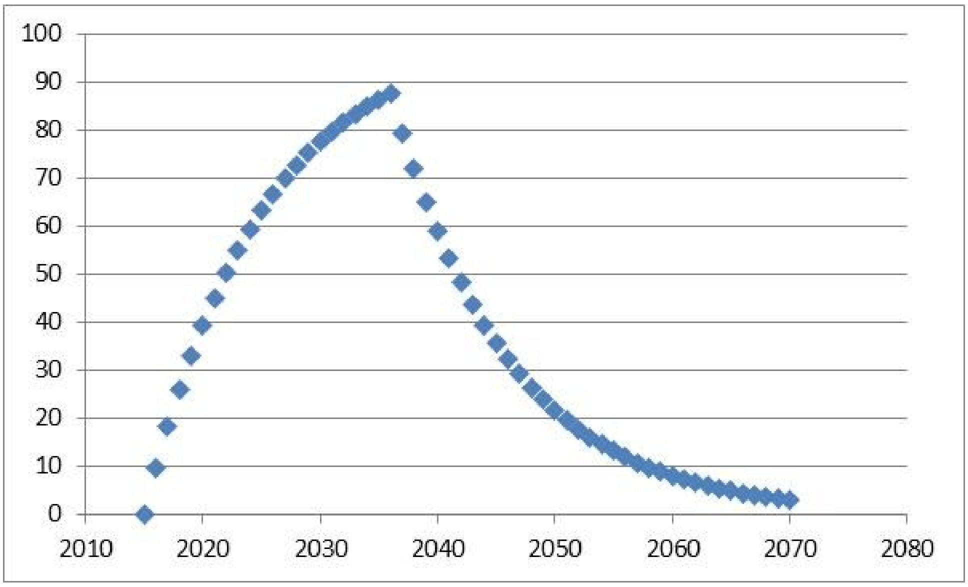

Figure 13: Development of the carbon stock if each year a product of 10 kg carbon with an average lifetime of 10 years is produced, starting in 2015 and ending in 2035.

Figure 12 and Figure 13 show that the historic production of a wooden product determines to what degree the current production contributes to an increase in carbon stock. Products that are produced for years and years or have a short lifetime have a low additional carbon storage impact; the inflow of these products just ensures that the existing carbon stock stays intact. New bio-based products or expanded production of traditional wooden products have a higher potential to create new carbon stocks, especially if they have a long lifetime. If the historic production of a wooden product or the wood sector is unknown, it is not possible to determine the current contribution of this product or the sector to additional carbon storage by using the IPCC HWP model.

The method described above is a theoretical model. In practice it will be difficult to verify the average lifetime and the spread in the likely lifetime of bio-based products like paper, panels and sawn wood as this would require to trace a large number of these products during the use phase. On the other hand, it should be possible to estimate the expected lifetime of products. Despite these difficulties, the basic idea of the model stands: given the limited lifetime of bio-based products, the carbon pool of these products will eventually get saturated at a certain point in time, as illustrated in Figure 12.

6.3 Application of the IPCC HWP model: the case of wood

Figure 14 shows that when assuming equal yearly production volumes, the carbon stock of panels and sawn wood still increases after 100 years, while products with a short lifetime like paper do not contribute significantly to carbon storage.

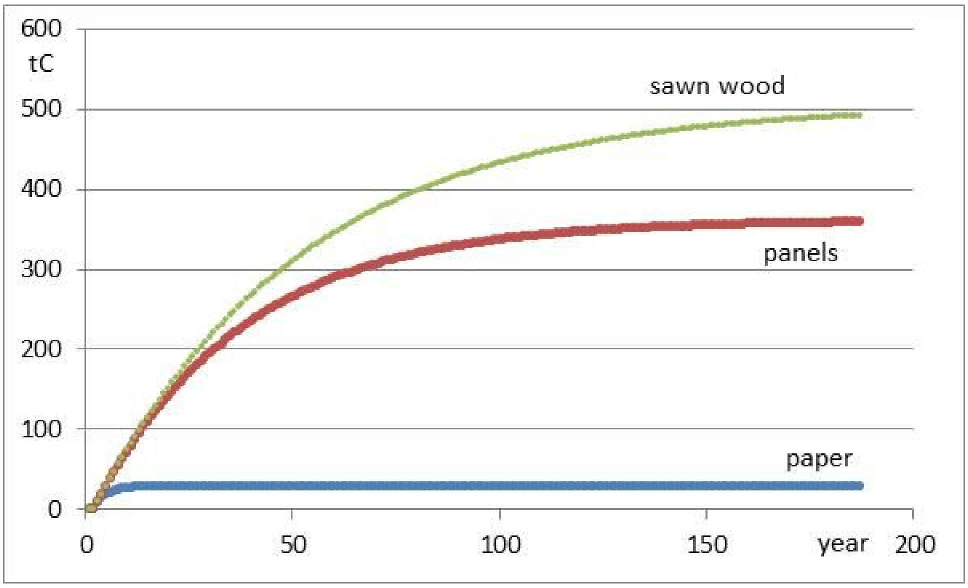

Figure 14: Development of the carbon stock if each year 10 kg carbon is produced in paper, panels and sawn wood, with an average lifetime of 3, 36 and 50 years, respectively. Source: Calculated according to the first order decay model as presented in Decision 259/2013/EU.

Figure 15 shows the development of the carbon stock of harvested wood products based on annual sawn wood production in the EU28 since 1900. For the years before 1961, no FAO statistics were available, therefore it is assumed that the sawn wood production each year in the period 1900-1960 equalled the average production in 1961-1965, the first 5 years for which statistics are available, following the guidance provided by IPCC (2013) (equation 2.8.6 on page 2.121). The slope of the graph shows that the carbon stock of sawn wood has still been growing in recent years. Based on the production and additional carbon stock during the last five years for which statistics are available (the period between 2009 and 2014), each tonne of carbon in produced sawn wood products led to 0.31 tonne of additional carbon storage. This means that the Additional Carbon Storage Factor (ACSF) of sawn wood is 31%. The chosen time period of the last 5 years is somewhat arbitrary; if a period of the last 10 years (2005-2014) would be chosen, the ACSF would be 34%, if only the data of the last year (2014) would be taken, the ACSF would be 31%.

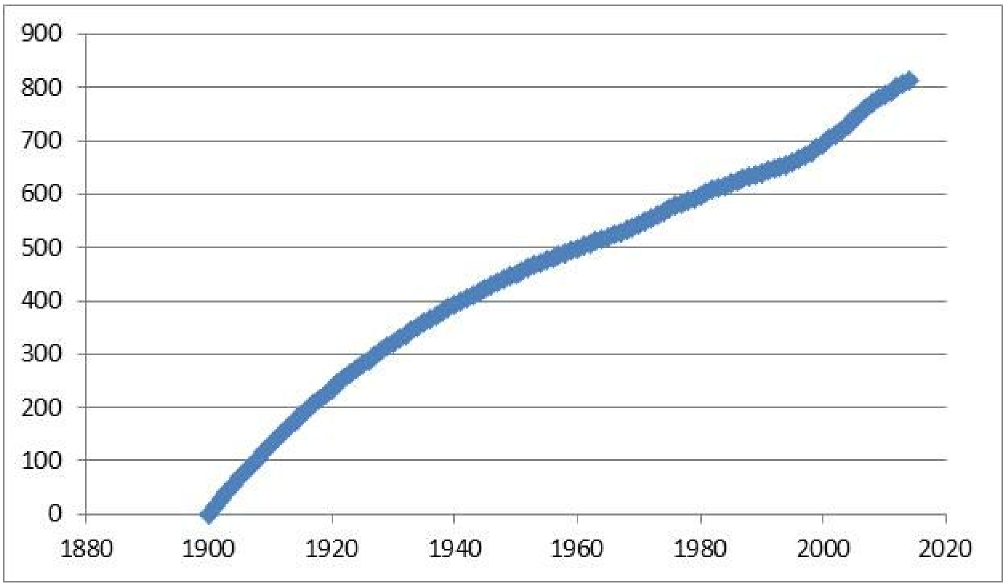

Figure 15: Development of carbon stock (in M tonnes carbon) based on sawn wood production in the EU28 since 1900. Source: FAOstat applied to HWP model Note: It is assumed that sawn wood production before 1961 equals the average production of 1961-1965 (following IPCC (2013) p 2.121).

Figure 16 shows the development of the carbon stock of wood based panels in the EU28. FAO statistics were only available after 1961. It is assumed that panel production before the year 1940 was zero, and that the panel production each year in the period from 1940-1960 equals the production of 1961-1965, the first 5 years for which statistics are available, following the guidance provided by IPCC (2013)[17].

The slope of the graph shows that the carbon stock of wood based panels is still growing substantially. Based on the production and additional carbon stock during the last five years for which statistics are available (the period between 2009 and 2014), each tonne of carbon in produced sawn wood products led to 0.37 tonne of additional carbon storage. This means that the Additional Carbon Storage Factor (ACSF) of sawn wood is 37%. The chosen time period of the last 5 years, is somewhat arbitrary; if a period of the last 10 years (2005-2014) would be taken the ACSF would be 50%, if only the data of the last year (2014) would be taken, the ACSF would be 34%. The panel production peaked in the period 2004-2008 and dropped during the economic crisis, leading to a considerably higher ACSF over 10 years compared to the ACSF over 5 years.

[17] See IPCC (2013), equation 2.8.6 on page 2.121

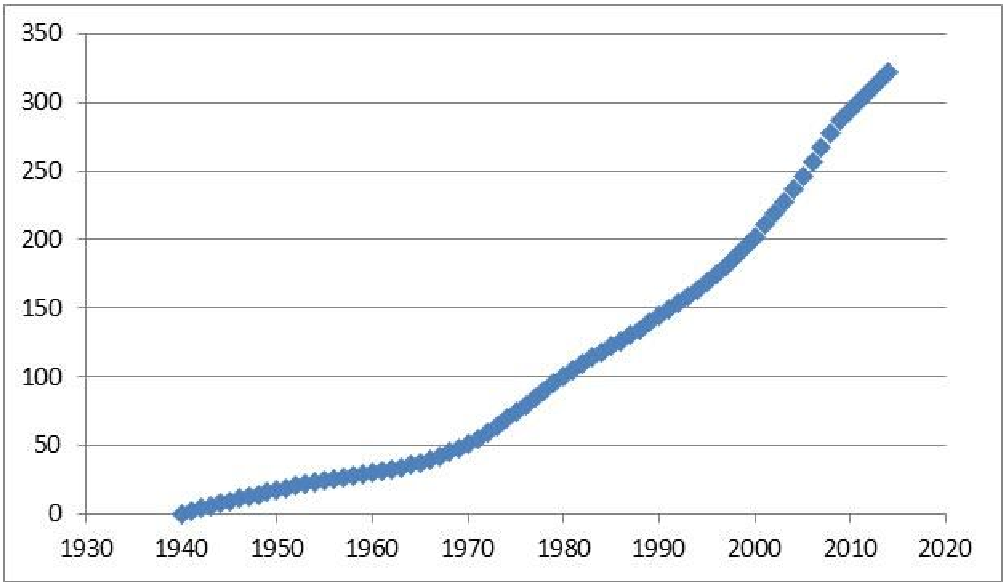

Figure 16: Development of carbon stock of wood based panels (M tonne carbon) in the EU28 since 1940. Source: FAOstat applied to HWP model Note: It is assumed that wood panel production from 1940-1960 equals the production of 1961-1965 (following IPCC (2013) p 2.121).

It is provisionally concluded that Additional Carbon Storage Factor (ACSF) of sawn wood in the EU28 is 31% and the ACSF of wood based panels 37%.

Comparison with wood flow analysis

Wood flow analysis provides an overview of the wood flows that take place within one year (Mantau, 2012). This type of flux data methods does not provide insight into the historical development of production of wood products that would be needed to feed into the IPCC HWP model. However, it shows the amount of panels and sawn wood produced in a year and the amount of wood that is lost or recovered in the same year. If these two figures are combined, the remainder is the additional carbon storage (in Figure 17 called „storage in use") of that particular year.

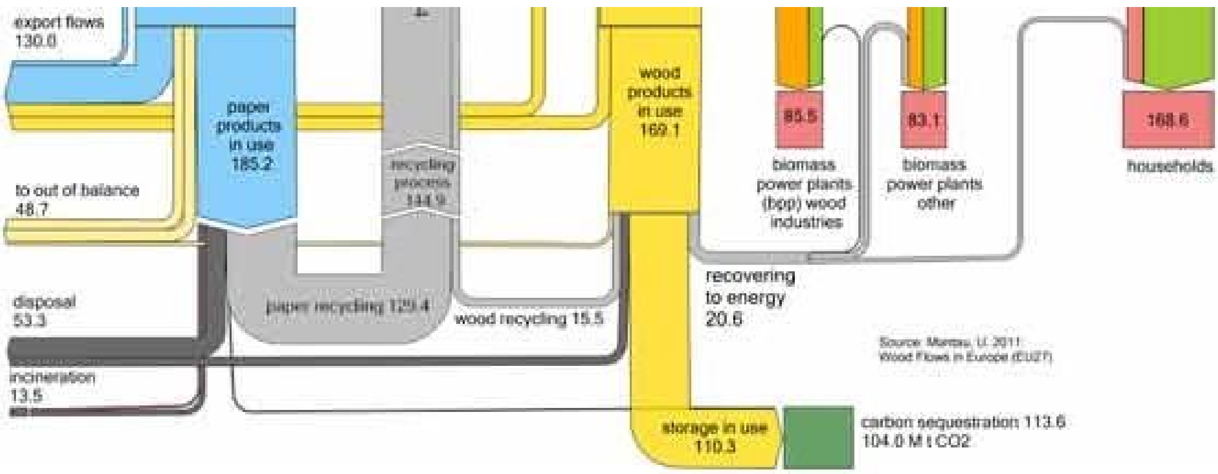

Figure 17: Detail of wood flows in EU27 (Mantau, 2012) showing that the production of wood products (wood products in use) is larger than the disposal, resulting in a net increase of carbon stock.

According to the wood flow model in 2010 the inflow of wooden products from sawn wood and panels (excluding paper) is 169.1 M m^3 swe, while the combined outflow of recovered wood and wood going out of balance (incineration and landfill) is only 58.8 M m^3 swe, resulting in a net inflow of harvested wood products of 110.3 M m^3 swe, representing a net contribution of 27.6 M tonnes carbon[18], or 106 M tonnes of CO_2[19] stored in harvested wood products (panels and sawn wood). This indicates that according to wood flow analysis (Mantau, 2012) the carbon pool in harvested wood products is still expanding and that the carbon pool is not yet saturated.

Table 10: Estimation of expected yearly outflow of wood based on the HWP model, based on the inflow according to wood flow analysis (in M m^3 swe)

	Sawn wood	Panels	Total
Inflow (wood flow analysis, data 2010)	96	72	169
Additional Carbon Storage Factor (ACSF)[a)]	37%	53%	-
Additional carbon storage	35.5	38.2	73.7

[a)] Please note that the 5 years ACSF of the period 2006-2010 is used, as the data of the wood flow analysis has base year 2010.
Source: own calculations combining the ACSF factor with wood flows from Mantau (2012)

In Table 10 the amount of additional carbon storage is calculated using the ACSF factors (37% and 53% for sawn wood and panels, respectively related to the period 2006-2010) and the wood flows as presented in (Mantau, 2012) with base year 2010. According to wood flow analysis the finished wood products in use consist of 169.1 M m^3 swe, of which 72 M m^3 consists of panels and 96 M m^3 of sawn wood. Table 10 shows a total carbon storage of 74 M m^3, which is substantially lower than the carbon storage of 110.3 M m^3 as found with wood flow analysis. The difference can partly be explained by limitations in the reliability of the data used in wood flow analysis; part of the wood going out of balance (landfill, incineration) might not be accounted for due to lack of reliable statistical information, resulting in an overestimation of the amount of carbon stored in products. This problem is recognised by IPCC (2013)[20]. They regard it good practice to rely on service life information, rather than on incomplete discard information (e.g. waste statistics).

Moreover, rough assumptions have been made on sawn wood and panel production before 1961, as no FAO statistics are available for this period. The build-up of the carbon pool in early years has a significant impact on the expected additional carbon storage in later periods. Moreover, the HWP model is just a mathematical model with assumptions on the average lifetime of products which are difficult to verify. Nevertheless both approaches show that the carbon stock in harvested products is still likely to increase.

[18] Assuming 500 kg/m^3 swe and 50 wt % carbon in wood.
[19] Molar weight of CO_2/C equals 44/12=3.67
[20] Section 2.8.4, page 2.124

6.4 Expected service lifetime of bio-based products

The potential of additional carbon storage of bio-based products strongly depends on the expected service lifetime of the products into which the bio-based product is processed. The method is not so relevant for packaging materials, surfactants, lubricants, cosmetics and detergents, which are expected to have a lifetime below 3 years, but much more for materials used in construction and - to some extend - vehicles that have a much longer service lifetime. See (Jan Van Dam & Van den Oever, 2012) for a catalogue of bio-based building materials (in Dutch). Below, an indicative table is made of bio-based materials, typical applications, and their expected service life (Table 11). When it comes to volumes, the traditional sawn wood and panel products are dominating the market.

Table 11: Typical applications and expected service life of bio-based materials

Bio-based material	Application	Estimated service lifetime (years)
Polyurethane (PUR)	Building and construction (27%), transportation (24%), furniture and bedding (21%)[21]	Construction:50 years [a)] Transport:18 years[b)] Furniture 15 years[c)]
Polyethylene (PE)	Packaging	< 3 years [c)]
Polyethylene Terephthalate (PET)	Bottles, packaging	< 3 years [c)]
Polylactic Acid (PLA)	Packaging	< 3 years [c)]
Natural fibres	Cars and lorries	18 years [b)]
Wood plastic components	Decking (67%) auto-interior parts (24%)[22]	36 years [c)] 18 years [b)]
Sawn wood	Construction	50 years[a)]
Panels (particle board, MDF, OSB, plywood)	Construction	36 years [a)]
Bio-based bitumen	Asphalt, roofing	15 years [c)]
Insulation materials	Construction	50 years [c)]

[a)] Based on IPCC (2006) [b)] https://www.vwe.nl/Actualiteiten/Nieuws/autos-op-steeds-oudere-leeftijd-gedemonteerd; [c)] Estimation BTG

6.5 Incorporating carbon storage in sustainability certification schemes

Carbon storage can be included in a sustainability certification scheme in a user friendly way, if Additional Carbon Storage Factors (ACSFs) can be provided that are robust and transparent to verify. The ACSF can be multiplied with the bio-based carbon content and the weight of the product resulting in the carbon storage of the product.

The challenge is not the application but the determination of the ACSF. The ACSF depends on all model parameters of the IPCC HWP model, meaning that the following information has to be found:

[21] The Socio-Economic Impact of Polyurethanes in the United States from the American Chemistry Council" The Polyurethanes Recycle and Recovery Council (PURRC). February 2004.
[22] Source: nova (2013) Market developments of and opportunities for bio-based products and chemicals.

- Production statistics of the bio-based product. FAO Statistics on wood are available since 1964, while the collection of statistics on innovative bio-based product is still in its infancy. It is expected that research to be executed in the coming years, e.g. supported by EU Horizon 2020 funding, will improve this situation.
- For the proposed method of carbon storage accounting it is important to determine a base year. For wood products this base year was 1900, and numbers in the period of 1900-1964 had to be estimated following an agreed method. For innovative bio-based products the year of the commercial introduction of the product could be taken as base year. For traditional bio-based products the year 1900 may be assumed.
- Average product lifetime. As already mentioned, it will be difficult to verify the average lifetime and the spread in the likely lifetime of bio-based products as this would require to trace a large number of these products during the use phase. However, it should be possible to estimate the expected lifetime of products.
- As noted in section 6.3 the timeframe of the ACSF (i.e. does it take the carbon storage calculation over only the latest available year, or the average over the past 5 years, or even 10 years) influences the outcome. It can be worth considering a period of at least a few years, to avoid a large influence of small fluctuations in production of the bio-based product in one or two years on the ACSF.
- Given the multitude of bio-based products, it could be useful to investigate further if ACSFs can be determined for groups of products.

Next to these methodological and data collection challenges organisational issues can be anticipated. In the first place, calculation of ACSF for different product groups will be quite an effort that could best be carried out by a respected research institute. For instance, in case of the sustainability certification of the RED recognised biofuels sustainability schemes the emissions factors of fossil fuels like gasoline, diesel and electricity from the grid are determined by JRC. The numbers are updated once every few years to reflect changes in emission factors and methods. Given that sustainability certification of bio-based products is voluntary, this approach might not be duplicable. The board of the voluntary scheme could, however, hire a known research institute and incorporate the numbers in a voluntary scheme or refer to scientific literature. Furthermore, the ACSF, although giving the right credits to the carbon storage potential of bio-based products, will be difficult to explain to the general public, since it is a rather complex topic. On the other hand, this is true for more bioenergy related topics, like ILUC.

6.6 Conclusion

Bio-based products with a long lifetime could become carbon pools especially during periods of rapid expansion of their production replacing fossil products. Temporary carbon storage is, by definition, reversible. On the long term, most carbon stored in products will eventually be released, however, it can be beneficial to store carbon on a short term (within the next 100 years), buying time to further develop a low carbon economy. The IPCC model for harvested wood products (IPCC HWP model) can be used to determine carbon pools in other bio-based products as well. The relative contribution of a single product to carbon storage can be expressed in an “Additional Carbon Storage Factor” (ACSF), a concept introduced in this report. While the application of ACSFs is straightforward, its determination is more challenging. The ACSF depends on all model parameters of the IPCC HWP model, requiring production statistics of the bio-based product and average product lifetime, and of course the bio-based content. Given the multitude of bio-based products, it could be useful to investigate further if ACSFs can be determined for groups of products. The question remains whether carbon storage is an issue to be communicated to the public, as it is rather complex and temporary. However, if it is decided to address the topic, the proposed ACSF could contribute to its quantification in a balanced way, taking into account its potential and the eventual saturation of these carbon pools.

7 Cascading of bio-based products

As discussed in section 3.7, cascading use is the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system. In a single stage cascade, biomass is processed into a product and, after its use phase, this product is used once more for energy purposes; in a multi-stage cascade, biomass is processed into a product and this product is used at least once more in material form before disposal or recovery for energy purposes (Vis et al., 2016).

Any bio-based product forms a single stage cascade if the product is used for energy and not sent to landfill. Bio-based producers can promote multistage cascading by providing products that are suitable for another stage in the cascade and/or by using tertiary biomass that was used in a product before, as input. For instance, construction and demolition wood can be used as input material for the production of wood plastic composites (WPC); moreover, WPC can be recycled into new WPC if an appropriate WPC collection scheme would be in place.

7.1 Limiting the energy use of biomass usable for material application

The cascading principle prefers material applications over direct energy use of biomass. As such, promotion of cascading use directly promotes bio-based products. It will be difficult to promote cascading use of biomass in a rigid way, e.g. by forbidding the energy application of materials suitable for cascading use. Bioenergy incentive schemes could however be designed in a way that the most suitable types of biomass, like for instance untreated package wood (pallets) are not incentivised. Voluntary sustainability certification schemes are free to apply criteria on cascading use. Sustainability certification schemes could include a reporting obligation on whether the use of the biomass does not displace its application in food and materials, as introduced in the Better Biomass scheme. One step further would be the introduction of a note “responsible cascading use” attached to the sustainability certificate, similar to the “low ILUC risk” note that is found in some existing sustainability certification schemes. This label would depend on the application of the biomass, not on the production of the biomass, and can therefore only be supplied to end users of the biomass. The most rigorous step would be not to certify biomass for energy if it has still a possible material or food application. This final step has the disadvantage that biomass in principle suitable for material application but in practice not available because of absence of material application of the biomass in the vicinity of the biomass production facility, is excluded from certification.

7.2 Promoting design for reuse

The possibilities of cascading use of a bio-based product depend strongly on the design of the product. Below, some of the general design requirements to improve cascading use of materials are listed (compiled from (Sirkin & Houten, 1994)):

- Avoiding processes like gluing, lamination, chemical bonding etc. as products of this nature cannot be returned to the same product cycle from which they originated;

- Reducing disassembly time by reducing the number of actions needed to separate the individual parts and materials, and using as few connectors as possible;
- Minimising the number of different materials in a product eases separability;
- The application of modular systems can increase the separability, and exchangeability as well aiding in the reduction of number of materials;
- Minimising the number of parts in the product, which will reduce assembly time, disassembly time and number of different materials;
- Keeping the next use in mind (use of certain inks could make paper recycling impossible); and
- Taking into account existing recollection systems for the re-use paths of chosen resources.

From a value chain perspective, it is rational to take into account the next use of the materials in the product; however, this is not necessarily the case at the level of an individual producer. Ensuring that the materials present in product A can be reused in product B might require an additional effort from the manufacturer of product A, while this manufacturer might not gain any benefits from their efforts. Moreover, the benefits of taking into account cascadability as part of the design process only become tangible after the end-of-life of the product, which can take many years. Part of the consumers might have specific interest in green recyclable products, but not all of them, especially if the product is more expensive due to taking into account cascadability. In order to reach the group of consumers with interest in recyclability, they need to be informed about the properties of the products. A traditional biomass sustainability certification scheme is focussed on the production of the biomass and might not be the best way to tackle this aspect. Product labelling could be a better way forward. For instance, eight voluntary furniture eco-labelling schemes exist in the EU, which inform among others about recyclability and harmful matter content (Vis et al., 2016) (p. 307)[23].

7.3 Promoting end-of-life options of bio-based products

For different bio-based products, different end-of-life options are possible. Ideally, plastics should be mechanically recycled as often as is feasible prior to their "final" recycling in the form of incineration or – where possible – composting or anaerobic digestion. Mechanical recycling refers to the various mechanical processes, including grinding or milling and subsequent melding used to recover waste plastics and ultimately to product regranulate from which new products can be injection moulded, extruded, thermoformed, blow moulded or otherwise produced (Thielen, 2016). Many biodegradable plastics can be mechanically recycled, the final recycling step will be composting. Standards and associated labels exist to show whether a plastic component is compostable or suitable for anaerobic digestion. Within the Open-Bio project, different standards and test methods on end-of-life options of bio-based products have been reviewed, tested, and improved. See for instance Deliverable

[23] See for instance the EU Ecolabel for wooden furniture: http://ec.europa.eu/environment/ecolabel/documents/Wooden_furniture.pdf

reports D6.1 Review on centralised composting, D6.3 Review on decentralised composting and D6.6 Review on standards for biogasification. This work facilitates ensuring that bio-based can be properly treated in the next stage of the cascade as recycled plastics, compost or biogas (energy).

7.4 Conclusion

Cascading use has a strong link with the application, but less with the production of biomass. Biomass sustainability certification schemes could provide end users an indication of "responsible cascading use" of biomass, indicating that cascading principles have been maintained, not using biomass for energy that still could be used for material applications. Ecolabelling is a suitable instrument to indicate that the bio-based product has been designed for reuse. Standards for end-of-life options of bio-based products can facilitate cascading use of bio-based products into new bio-based products, compost or energy.

8 Bio-based (carbon) content in biomass sustainability schemes

8.1 Introduction

Bio-based products can be partly or wholly derived from biomass. Bio-based content measurement methods distinguish between bio-based content and fossil content of a bio-based product. The bio-based content of a product can be produced with sustainable or non-sustainable biomass. Biomass certification schemes can be used to certify that the bio-based content of a bio-based product has been produced in a sustainable way, meeting the sustainability criteria of the applied scheme. Both bio-based (carbon) content and sustainability of the biomass need to be verifiable throughout the supply chain. The applicability of different chain of custody models depends on whether the sustainability attribute and the carbon content of the bio-based product should be physically present in the final product. The approach in which bio-based carbon content is always physically available in the bio-based product can be regarded mainstream, and it is probably the most certain way to obtain consumer acceptance. The requirement of physical presence of bio-based content in the bio-based product has consequences for the applicability of the chain of custody models currently used in biomass sustainability certification schemes. In this chapter it is investigated how biomass sustainability schemes that currently allow certification of bio-based products, i.e. NTA8080, RSB and ISCC deal with this issue, and is sought for general recommendations on the application of chain of custody models for bio-based products, in particular for the different variations of the mass balance approach.

8.2 Determination of bio-based (carbon) content

Biomass is an important feedstock for many products. The wood sector generates semi-finished products such as sawn wood, panels, paper and finished products like buildings, furniture, books, etc. The wooden input in the product will often be visibly recognisable for the user. In case biomass is used to produce bio-based chemicals, it will be more difficult to recognise if and what part of the products are bio-based, especially if it concerns drop-in bio-based chemicals that are chemically identical to fossil based chemicals, but also bio-based ingredients in mixtures like a liquid soap will be difficult to recognise. Determination of the bio-based content of a product can be performed *directly* by measuring the bio-based carbon content in the product or *indirect*ly by calculating the share of bio-based in a product by analysis of all inputs to the production process.

8.2.1 Direct bio-based (carbon) content methods

Radiocarbon method supplemented by elemental analysis (EN 16785-1) is the standardised method used for the determination of bio-based carbon content and total bio-based content. Application of EN 16785-1 to a certain product results in a fixed number for the bio-based content of the product, describing which fraction of the product originates from biomass. Bio-based carbon content is derived from radiocarbon analysis (see Box 1). Total bio-based content (now also considering hydrogen, oxygen, and nitrogen atoms) is calculated according to the following rule: *If oxygen (O) and/or hydrogen (H) and/or nitrogen (N) element(s) is(are) bound to a carbon structure derived from biomass, its(their) fraction is(are) considered to be part(s) of the bio-based content* (EN 16785-1).

Box 1: Radiocarbon method explained

Radiocarbon or carbon-14 originates in the upper atmosphere of the earth and is created when neutrons originating from solar radiation bombardment collide with nitrogen in the air. A reaction occurs and a tiny number of these collisions convert nitrogen to carbon-14. This carbon-14 immediately starts to radioactively decay but is constantly being recreated. This leaves the amount in the air relatively constant.

Living plants are active components of the overall food chain. Animals eat plants and/or other animals; humans eat plants and animals. Therefore, all living plants, animals, and human beings have the same amount of carbon-14 in their bodies at the same time. Their bodies are said to be in "equilibrium" with carbon-14 in the air.

When a plant stops assimilating carbon dioxide or when an animal or human being stops eating, the ingestion of carbon-14 also stops and the equilibrium is disrupted. From that time forward, the only process at work in the body is radioactive decay. Eventually, all the carbon-14 in the remains will disappear. This principle applies equally to a person dying, a corn stalk being cut down, or to a soybean plant being pulled out of the ground. When they stop living, they stop taking in carbon-14 from the air around them, and the amount of carbon-14 in the remains gradually disappears.

A radiocarbon dating laboratory is able to measure the amount of carbon-14 remaining in a fossil. It then uses this information to determine the last time the fossil was respiring carbon (i.e. eating or photosynthesizing). A radiocarbon dating lab is able to do this using the known "half-life" of carbon-14. The half-life of carbon-14 is the amount of time it takes for one-half of the original amount to disappear by radioactive decay. This half-life is about 5,700 years and means that every 5,700 years the amount of carbon-14 in a fossil is only one-half of what it was 5,700 years ago. It also means that if a dead plant has 50% as much carbon-14 in it than in a living plant, the dead plant was alive about 5,700 years ago.

After 50,000 years, a fossil won't have any radiocarbon left in it. Carbon-14 will have all disappeared by radioactive decay. When a radiocarbon dating lab doesn't see any carbon-14 in a fossil, it knows the fossil is more than 50,000 years old. Petroleum and dinosaur bones are examples of fossil materials that no longer have carbon-14 remaining in them.

Source: excerpt from http://www.betalabservices.com/bio-based/carbon14-dating.html

NEN initiated the development of a European certification scheme[24] for bio-based carbon based on EN 16785-1. The applicant contracts a certification body and a testing laboratory which is recognized by the certification body. The certification body validates the data provided by the lab. If the outcome is positive, then the applicant receives the certificate and is listed in central register of certificates.

[24] See www.bio-basedcontent.eu

Stable isotope analysis is now most used for detection of the geographical origin, food authentication and in forensic analysis. This could be useful if there is doubt on the origin of biomass contained in a bio-based product. In Open Bio (Deliverable D3.2) it is investigated if stable isotope analysis can be used for the determination of bio-based content as an alternative to the radiocarbon method. The results of the investigations indicate that neither stable isotope analysis of the carbon isotope (δ13C) alone, nor stable isotope analysis of carbon, hydrogen and oxygen isotopes (δ13C, δ2H and δ18O) combined can be conclusive with respect for the determination of the bio-based content in the selected product. Nevertheless, despite that stable isotope analysis cannot be used to obtain a certain number for the bio-based content of a product, multiple stable isotopes analysis is widely used to obtain some indications on the geographical origin of the materials and or feedstock.

8.2.2 Indirect bio-based content methods

The average bio-based content of products can be determined by measuring the amounts of fossil and biomass based materials in a production process. The draft Standard prEN 16785-2 *"Bio-based products – bio-based content – part 2: Determination of the bio-based content using the material balance method"* provides guidance on how to determine the bio-based content in case of chemical or biological reactions and in case of formulation or assembling. If reactants are derived from both biomass and a fossil resource, the basic chemical or biological reaction rules apply for the allocation of the elements. If oxygen and/or hydrogen and/or nitrogen elements are bound to a biomass carbon structure, their fraction is considered to be part of the bio-based content. The method requires that all inputs, outputs, losses and their bio-based content are known.

(Clark et al., 2015) have studied and tested various indirect bio-based content methods, which served as input to the above-described draft standard prEN 16785-2. They make a distinction between mass balance approaches and atom connectivity methods, the latter focussing on the allocation of non-carbon elements as part of the bio-based product in chemical reactions between bio-based and fossil based chemicals. One example of an alternative mass balance approach, different from the material balance of prEN 16785-2, is the method developed by TÜV-SÜD for BASF. It focusses on the determination of the amount of fossil carbon saved by introducing biogenic carbon in the production process. If multiple products are produced like in refineries, the method allows attribution of the fossil carbon savings expressed in methane energy equivalents to a particular product. The claim attached to this product is not being a bio-based product but "contributing to fossil resource savings in the production process". Please note that the fossil/renewable energy needed in the production process is not considered here, only the fossil/renewable carbon in the product itself. This example shows that indirect-carbon methods are available that attribute the use of biomass to a certain product, without the necessity that the product itself is bio-based. The draft standard prEN 16785-2, however, does not support such an attributional approach, and can only be used to determine the real (guaranteed minimum) physically present bio-based content of a product.

8.3 Bio-based content determination in existing certification schemes relevant for bio-based products

RSB, ISCC and NTA8080 are three biomass sustainability certification schemes facilitating certification of bio-based products, Table 12 summarises the criteria of these schemes related to bio-based content.

Table 12: Specific criteria on bio-based content in NTA8080, RSB and ISCC

Topic	NTA8080	RSB	ISCC
Minimum bio-based content	No	25%[a)]	No
Reporting of bio-based content	Yes	Yes	Yes
Measurement method bio-based content	Direct (EN 16785-1:2015[b], EN 16640:2014[c]) and indirect (EN 16785-2:2015[d])	Direct (ASTM D6866[e], CEN/TS 16137[f], or any equivalent protocol)	Direct (ASTM D6866, or CTN/TS 16137)

[a)] annual average; [b)] EN 16785-1 'Bio-based products – Bio-based content – Part1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis; [c)] CEN/TS 16640:2014 'Bio-based products - Determination of the bio based carbon content of products using the radiocarbon method'; [d)] prEN 16785-2 'Bio-based products – Bio-based content – Part 2: Determination of the bio-based content using the material balance method'; [e)] ASTM D6866 – 12. Standard Test Methods for Determining the Bio-based Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis; [f)] CEN/TS 16137:2011 Plastics - Determination of bio-based carbon content.

Within the NTA8080-1:2015 no statement on the minimum level of bio-based content is made. If a bio-based product is partly bio-based, the claim "bio-based" should be accompanied by a quantification of the bio-based content, based on direct carbon content measurement methods, which are wholly or partly based on radiocarbon content measurement methods such as found in CEN/TR 16640 and EN 16785-1, or indirect material balance method as described in EN 16785-2.

RSB (RSB, 2015b) requires that the bio-based carbon content of the product shall be based on a 12 month average and shall not be less than 25% (by weight). Bio-based chemicals producers and bio-based product manufacturers shall determine the bio-based content of their products based on ASTM D6866, CEN/TS 16137 or any equivalent protocol, which are all direct (carbon) content methods. In case the bio-based content can fluctuate throughout the year, these direct methods obviously have to be accompanied by a mass balance method to determine the 12-month average carbon content. In fact, it is possible to produce 6 months with fossil input only and 6 months with 50% bio-based carbon content and still meet the requirement of a yearly average of 25% bio-based carbon content. This was, however, never the intention of RSB (Schmidt, 2016) and in a future update of the scheme this requirement will probably adjusted in a way that the bio-based material is always physically available in the material. Moreover, in a future update, the minimum requirement of 25% carbon content might be replaced by a statement of the actual bio-based content.

ISCC does not have a minimum requirement for the share of biomass used in the bio-based product. ISCC (ISCC, 2015) requires that in case of partly bio-based products the bio-based content is directly measured by a radiocarbon method in accordance to ASTM D6866 and/or CEN/TS 16137, and that the percentage of bio-based product is mentioned. Alternatively, in case of bio-based materials that are used in drop-in processes the bio-based content and sustainability in the final product can be freely allocated. In the latter case the claim must refer to the effort to contribute to the responsible sourcing of bio-based products or to the saving of fossil resources, but no statement shall be made that the product itself is bio-based.

8.4 Bio-based content methods and chain-of-custody models for traceability

Bio-based content methods distinguish between bio-based content and fossil content in a bio-based product. Bio-based content can be made of both sustainable and non-sustainable biomass. See Figure 18.

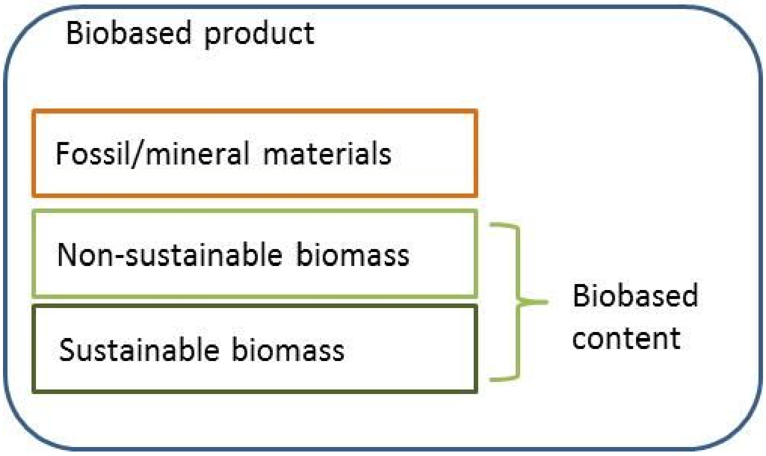

Figure 18: Bio-based content can be produced from both sustainably produced and non-sustainably produced biomass

The chain of custody models in the sustainability schemes are originally designed to certify the sustainability of the biomass. In this section it is investigated what impact the bio-based content requirement has on the applicability of these chain of custody models.

Table 13Table 13 shows an overview of the chain of custody models for traceability allowed in NTA8080, RSB and ISCC for certification of bio-based products. All three certification schemes support physical segregation where the sustainable biomass can be physically tracked through the supply chain as well as different types of mass balance approaches.

Table 13: Allowed chain of custody models for traceability for bio-based products

Topic	NTA8080-2:2015	RSB	ISCC
Segregation - identity preserved	Yes	Yes	Yes

Segregation - it can include mixture of certified biomass	Yes	Yes	Yes
Mass balance - transfer of sustainability claim to other biomass products possible	Yes	Yes	Yes
Mass balance - transfer of sustainability claim to fossil products possible	Yes[a)]	Yes[c)]	Yes
Mass balance - fluctuation of certified/non certified material over defined period of time allowed	No[b)]	Yes[c)]	Yes
Book and claim	No	No	Partly[d)]

[a)] At the same time the physical bio-based content of the final product has to be mentioned.
[b)] NTA8080-2:2015 Art 5.3.3 states that no temporary shortage of sustainable biomass are allowed. The biomass must origin form a sustainable source continuously.
[c)] Strictly following the RSB standard this is possible, but this was never the intention of RSB (Schmidt, 2016).
[d)] Transfer of a claim between conversion units and warehouses within the same country or neighbouring countries is allowed (ISCC PLUS 204-01 mass balance requirements, section 5.4.2).

Physical segregation

In case of physical segregation, mixing certified and non-certified biomass is not allowed. The biomass part of the product consists for 100% of certified material and the material can be traced back to its origin. In case of “physical segregation - identity preserved”, no mixing with other certified biomass takes place. In case of both physical segregation methods, the consumer can be sure that the bio-based content is physically available in the product (which can be optionally be verified by a direct radiocarbon content method) and from a sustainable origin.

Mass balance

The mass balance option allows the physical mixing of batches, and the sustainability claim can be transferred to non-certified biomass/material in the mixture as long as the total amount of sustainable biomass input equals the total amount of sustainable biomass output.

<u>NTA 8080</u>

NTA 8080-2:2015 (NEN, 2015) distinguishes three mass balance models, (1) one in which certified and non-certified biomass can be mixed, (2) one in which in addition also fossil products can be mixed, and (3) a model in which the sustainable biomass content is claimed as a percentage of the total mixture.

- In model (1) the bio-based content is guaranteed as only 100% biomass is mixed.
- In model (2) mixture with fossil products and subsequent extraction of a batch from this mixture the physical bio-based content cannot be checked anymore with the administrative information of the mass balance alone[25]. NTA8080 allows the claim *“x% allocated biogenic of which y% is sustainably produced”*. However, in addition NTA8080 requires that the physical biogenic part is declared as well[26], which means that the bio-based carbon content of the extracted batch has to be determined using a direct method.

[25] Except if the bio-based content in the mixture would distribute perfectly, which is possible in case of liquid and gaseous products.
[26] See NTA8080-2:2015 paragraph 6.2 under a.

- In model (3) the bio-based content can be calculated provided that the bio-based content in the mixture would distribute perfectly, which is possible in case of liquid and gaseous products which are mixed in one physical unit. In this case the material balance method described in prEN 16785-2:2015 can be used.

NTA8080 does not allow temporary shortages of sustainable biomass in its mass balance approach (see Art 5.3.3 of NTA8080-2:2015). The biomass must originate from a sustainable source continuously. Contrary to RSB and ISCC no period of 3 months is defined in which the mass balance can be closed.

RSB

RSB (RSB, 2015b) allows the mass balance approach as chain of custody method for bio-based products, which can be used in case certified and non-certified biomaterials are mixed. The "participating operator" shall either track documentation associated with each batch of compliant physical product, or track the documentation of the product mix of different batches of RSB compliant physical product. Deficits of RSB certified materials may occur, as long as balance is achieved over a fixed period of time (max. 3 months). It seems that biomass and fossil products can be mixed. RSB Standard for traceability of RSB certified material (RSB, 2014) F3.5.3 states that *"You may physically mix RSB certified material with products that are not RSB certified".* Implicitly, the term "product" does not exclude fossil materials. Personal communication (RSB 2016)[27] confirmed that mixture with fossil products is allowed. Thus, the physical product in hands of the final consumer can be a mixture of certified and con-certified biomass, and possibly a mixture of biomass and fossil products, which means that direct bio-based (carbon) methods are needed to measure the (sustainable) bio-based content of the final product.

Personal communication with the Standards Director of RSB (Schmidt, 2016) made clear that 25% bio-based content should be physically measurable with direct carbon content methods at all times. This would mean that large fluctuations in bio-based carbon content as facilitated by the introduction of a 12-month average are not desirable. Consequently, the above described mass balance chain of custody approach could only be applied to sustainable and non-sustainable biomass before a bio-based product containing fossil materials is produced. After production of the bio-based product de facto only a physical segregation chain of custody can be applied to guarantee that the 25% bio-based content is physically available in the final product. Alternatively, direct bio-based carbon content measurement could be applied after production of each batch of final products.

The transfer of a bio-based claim to a fossil product is not intended also because declaring a fossil product as being bio-based has the result that the original bio-based product should then be regarded "non-bio-based". It would be a bit odd to declare a sugar beet to be non-bio-based. Moreover, it can lead to fraud as for instance the fossil declared bioethanol has still the property of being bio-based, which can be proven with direct bio-based carbon

[27] Email with Elena Schmidt, RSB Standards Development Director.

methods. This can be solved by not claiming that the product itself is bio-based, but that the producer promotes sustainable production of biomass.

ISCC PLUS

ISCC PLUS is the ISCC certification system relevant for bio-based products. The mass balance chain of custody option of ISCC (ISCC, 2014) allows the physical mixing of batches while the bookkeeping for different sustainability attributes must be separated. If a physical mixture is split up, the sustainability attributes in the mass balance can be assigned to any physical batch. However, the sustainability attributes attached to a certain batch of output material must comply with the information on sustainability attributes in the company's mass balance. The mass balance can be continuous in time, in which case a deficit must not occur, i.e. at no point in time can more sustainable material be withdrawn than what has been added. Alternatively, the balance could be achieved over an appropriate period of time and regularly verified. The maximum timeframe for the ISCC mass balance calculation is three months. The mass balance must be site specific, e.g. the mass balance covers the biomass produced, converted, mixed or transported at one specific production location. However, conversion units and warehouses, which are only certified under ISCC PLUS are able to transfer positive credits to other conversion units or warehouses, which are located either within national borders or located in a neighbouring country. In this case the mass balance is not site specific anymore but setup at company level. It is close to a book and claim chain of custody approach as the products are physically not connected anymore.

ISCC PLUS requires that the bio-based content of partly bio-based products is mentioned, and verifiable by a direct method. If products are mixed and a mass balance approach is applied, direct measurement by a radiocarbon method will be needed for each batch, as the bio-based content is not in all cases calculable anymore. This is definitely the case when the mass balance is extended to company level and not site specific anymore. For drop-in bio-based products ISCC allows a free attribution of the bio-based content in products, which are partly derived from both biomass and fossil resources. In the latter case the mass balance approach can be applied without problems throughout the supply chain, as the bio-based carbon content does not need to be physically available in the products for which an ISCC claim is made.

8.5 Conclusion

Biomass sustainability certification schemes like NTA8080, RSB, and IPCC work with physical segregation and mass balance chain of custody approaches to trace the sustainability attributes of biomass. Mass balance methods allow sustainability attributes to be assigned to any physical batch from a mixture as long as the total mass balance is correct. This means that the certified biomass in hands of the consumer might not be produced sustainably, but it is guaranteed that a similar quantity of biomass has been produced sustainably elsewhere[28].

Contrary to the attribution of sustainability to a certain fraction of the mixture, which seems to be well accepted, attribution of bio-based content to a fossil product is often regarded risky and misleading to consumers. Therefore, NTA8080 requires that the physical bio-based content of any certified bio-based product is stated, along with a possible statement on the allocated biogenic content and the percentage sustainably produced biomass of this allocated biogenic content. RSB intents that at least 25% of the product is verifiably bio-based by direct (carbon) content measurement methods[29]. ISCC allows transfer of the claim that biomass is used in the production process to a particular final product in its mass balance approach, as long as clear claims are used and the certified output volumes do not exceed the equivalent amount of certified feedstock. This could help companies in the early stages of replacing fossil-based products with bio-based alternatives. There is another objection against transfer of bio-based content to fossil products: the transfer of bio-based content to a fossil product would result in biomass or a bio-based product that is not really biomass anymore, while the bio-based content is still detectable by ^{14}C direct carbon content measurement. It would create for instance bioethanol that is declared fossil, which is is a bit odd and has a certain risk of fraud.

If decided that physical presence of bio-based content in a product is necessary, this requires harmonisation with the more lenient approach of attribution of sustainability to a specific batch in a mixture, as applied in the mass balance chain of custody model.

- In case of physical segregation, the sustainable biomass and thus the bio-based content are followed physically, therefore as long as the bio-based content of all input materials are known, the bio-based content of the final product can be calculated, following indirect methods such as prEN 16785-2.

[28] NTA 8080 allows in case of the mass balance for bioenergy a claim of 100% sustainably produced biomass to the allocated biomass; in case of bio-based products the allocated sustainable produced part of the allocated biogenic part of the product need to be mentioned. ISCC requires mentioning the applied chain of custody approach in the sustainability declaration, in case of mass balance implicitly stating that the sustainability of the biomass could be attributed (ISCC PLUS 203 Requirements for Traceability). RSB requires a more precise declaration: “product mix contains RSB compliant bio-products” or if RSB trademarks are used on packaging, dispensers and transportation equipment a statement such as “an equivalent mass of this bio-product originated from a production operation certified for compliance with RSB standards”(RSB-STD-02-01 RSB standard for certification of bioproducts).

[29] This, however does not match with the actual mass balance approach of RSB that requires that the mass balance is a 12 month average.

- Mass balance methods allow sustainability attributes to be assigned to any physical batch from a mixture as long as the total mass balance is correct. Mass balance methods can be used upstream in the biomass supply chain as long as it only concerns 100% biomass and no fossil products are mixed. As soon as a bio-based product is produced that contains a fossil component as well, a physical segregation method is preferred as this way it is ensured that bio-based content is available in the final product, without the need to determine the bio-based content of each batch by using direct radiocarbon methods.
- In case batches are physically mixed with perfect distribution of bio-based and non bio-based content, the average bio-based content of the final product can be calculated as a percentage of the total mixture. This is possible when liquid and gaseous products are mixed in one vessel.
- Book and claim approaches are in principle possible to apply as long as the supply chain works with 100% biomass. As soon as a fossil input is added to the bio-based product, the book and claim approach cannot be used onwards in the supply chain.

9 Conclusions and recommendations

This report identifies and explores sustainability issues relevant for bio-based products. It investigates what lessons can be learned from biomass sustainability schemes for bioenergy and biofuels and what topics that are currently not covered in biomass sustainability schemes mean for the sustainability certification of bio-based products.

Greenhouse gas emission reduction - LCA
Bio-based products are preferable over fossil based products because they often have environmental benefits. In case of bioenergy and biofuels, for example, greenhouse gas emission reduction is one of these key benefits. The GHG reduction calculation of bio-based products is often far more complex than that of biofuels. Existing sustainability schemes for biofuels and bioenergy do not offer much support here. Our review of LCAs of bio-based products showed that GHG emissions are considered in all considered assessments, but indirect factors influencing these emissions are considered to a highly varying degree. Diverging energy use indicators are applied (e.g. considering all energy sources vs. only non-renewable energy), and ILUC and carbon storage are addressed only sporadically. The newly developed European Standard EN 16760 introduces two approaches for modelling CO_2 emissions related to biogenic carbon and provides some guidance on GHG calculations in LCAs of bio-based products, mainly directing readers to other sources, such as the IPCC, RED or ISO standards. However, it does not solve all methodological problems and it confirms our finding that there is not yet a consensus on how to include ILUC in GHG emission calculations (EN 16760). Overall GHG emissions are an important sustainability indicator for bio-based products, but to address them more precisely in LCAs, more research is required. Aspects such as ILUC and carbon storage are currently rarely considered and there is no scientific consensus on appropriate methodologies. GHG emission reductions are not required by current sustainability schemes, though stakeholders and consumers deem them very relevant. Even though aspects like ILUC and carbon storage cannot yet be considered thoroughly, the review of LCAs showed that it is current practice to calculate and compare GHG emissions, and that there are well established impact assessments that address the emissions. Therefore, it is recommended to include GHG emission reduction calculations in sustainability schemes for bio-based products.

Indirect land use change
Indirect land use change could become an important topic for bio-based products using sugar, starch and oil crops, especially if the production of bio-based products would expand rapidly, like the production of biofuels did in the recent past. A division could be made between traditional bio-based products that have an established ILUC impact, and new (modern) bio-based products that have an additional land use impact that needs to be treated a newcomer with additional land use impacts like biomass produced for biofuels. None of the existing biomass sustainability certification schemes have implemented ILUC factors for agricultural biomass to compensate for indirect emissions elsewhere, as was proposed in EC proposal COM(2012)595 for the “ILUC Directive”. RSB and Better Biomass

stress the importance of this matter in their documentation, but see no possibilities to address this properly on farm level. Although ILUC modelling is still a relatively young field of expertise and can be further optimised, it will be very difficult to develop ILUC factors that take into account greenhouse gas emissions related to ILUC of different crops that have a high reliability at farm level. However, models like GLOBIOM can show which biomass feedstock have higher and lower ILUC risks. It would be good practice for producers of bio-based products to avoid high ILUC risk feedstock. Moreover, it is possible to apply a low-ILUC risk assessment offered by some biomass sustainability certification schemes (RSB and Better Biomass). The aspect of high and low ILUC risk could be covered by a bio-based product sustainability scheme without the need to use an exact ILUC factor.

Carbon storage in bio-based products

Bio-based products with a long lifetime could become carbon pools especially during periods of rapid expansion of their production replacing fossil products. Temporary carbon storage is, by definition, reversible. On the long term, most carbon stored in products will eventually be released, however, it can be beneficial to store carbon on a short and medium term (within the next 100 years), buying time to further develop a low carbon economy. The IPCC model for harvested wood products (IPCC HWP model) can be used to determine carbon pools in other bio-based products as well. The relative contribution of a single product to carbon storage can be expressed in an "Additional Carbon Storage Factor" (ACSF), a concept introduced in this report. While the application of ACSFs is straightforward, its determination is more challenging. The ACSF depends on all model parameters of the IPCC HWP model, requiring production statistics of the bio-based product and average product lifetime, and of course the bio-based content. Given the multitude of bio-based products, it could be useful to investigate further if ACSFs can be determined for groups of products. The question remains whether carbon storage is an issue to be communicated to the public, as it is rather complex and temporary. However, if it is decided to address the topic, the proposed ACSF could contribute to its quantification in a balanced way, taking into account its potential and the eventual saturation of these carbon pools.

Cascading use

Cascading of biomass is not a goal in itself but a means to contribute to resource efficiency targets as well as GHG emission reduction. In current preference orders bio-based products are usually placed below food/feed and above energy. However, benefits of cascades including bio-based products need to be compared to reference alternatives, in order to appreciate the benefits of the bio-based products properly, which can be achieved by an LCA covering the whole cascade. Cascading use has a strong link with the application of the biomass but less with the production of biomass. Biomass sustainability certification schemes could provide end users of biomass an indication of "responsible cascading use" of biomass, indicating that cascading principles have been maintained, not using biomass for energy that still could be used for material applications. Eco-labelling is a suitable and recommendable instrument to indicate that the bio-based product has been designed for reuse. Standards for end-of-life options of bio-based products should facilitate cascading use of bio-based products into new bio-based products, compost or energy.

Bio-based content and biomass sustainability schemes

Bio-based content methods distinguish between bio-based content and fossil content of a bio-based product. Bio-based content can originate from both sustainable and non-sustainable biomass. Biomass sustainability certification schemes like Better Biomass, RSB, and ISCC-PLUS work with physical segregation and mass balance chain of custody approaches to trace the sustainability attributes of biomass. Mass balance methods allow sustainability attributes to be assigned to any physical batch from a mixture as long as the total mass balance is correct. This means that the certified biomass in hands of the consumer might not be produced sustainably, but it is guaranteed that a similar quantity of biomass has been produced sustainably elsewhere.

Contrary to the attribution of sustainability to a certain fraction of the mixture, which seems to be well accepted, attribution of bio-based content to a fossil product is often regarded risky and misleading to consumers. If decided that physical presence of bio-based content in a product is necessary, this requires harmonisation with the more lenient approach of attribution of sustainability to a specific batch in a mixture, as applied in the mass balance chain of custody model. Mass balance methods can be used upstream in the biomass supply chain as long as it only concerns 100% biomass and no fossil products are mixed. As soon as a bio-based product contains a fossil component as well, a physical segregation method is preferred, as this way it is ensured that bio-based content is available in the final product, without the need to determine the bio-based content of each batch by using direct radiocarbon methods.

ANNEX A Introduction of Better Biomass (NTA8080), RSB and ISCC

Better Biomass (NTA8080)

NTA8080 is based on the Dutch Cramer Criteria, one of the first comprehensive sets of sustainability criteria for biomass. The NTA8080 version 2009 can be ordered at the web shop of the Dutch standards organisation NEN. In combination with the NTA8081 that describes the certification scheme, and the interpretation document 07 linked to NTA8081 (both available for free on http://www.duurzame-biomassa.org), a complete EU approved certification system is in place. In 2015 NTA8080 has published an updated NTA8080 that allows bio-based products to be certified. The sustainability criteria exceed the requirements of the RED, also related to greenhouse gas emission savings (50% after 2012 instead of 35% as required in the RED). The NTA8080 is based on nine guiding principles:

- Principle 1: The greenhouse gas balance of the production chain and application of the biomass is positive.
- Principle 2: Biomass production is not at the expense of important carbon sinks in the vegetation and in the soil.
- Principle 3: The production of biomass for energy shall not endanger the food supply and local biomass applications (energy supply, medicines, building materials).
- Principle 4: Biomass production does not affect protected or vulnerable biodiversity and will, where possible, strengthen biodiversity.
- Principle 5: In the production and conversion of biomass, the soil and soil quality are retained or even improved.
- Principle 6: In the production and conversion of biomass, ground and surface water are not depleted and the water quality is maintained or improved.
- Principle 7: In the production and conversion of biomass, the air quality is maintained or improved.
- Principle 8: The production of biomass contributes towards local prosperity.
- Principle 9: The production of biomass contributes towards the social well-being of the employees and the local population.

In addition, the draft updated NTA8080:2015 includes a reporting obligation for cascading and the possibility to certify biomass as “ILUC low risk”.

According to the NTA8080 website (http://www.betterbiomass.com/) two certification bodies can submit NTA8080 certification. So far (July 2016) 66 certificates have been submitted, for green gas, biodiesel, ethanol and for woody biomass.

Better Biomass NTA8080 and bio-based products

The certification scheme based on NTA8080-1:2015 has been renamed into "Better Biomass". This underlines its application possibilities for more than bio-energy feedstock as it includes the possibility to include bio-based products. The following requirements are set.

Greenhouse gas emissions:

- The organisation shall have access to the data on the greenhouse gas emissions.
- The organisation can use the Greenhouse gas emission calculation methodology as used in the Renewable Energy Directive (as presented in NTA8080, Annex D).
- No requirements are set on the net greenhouse gas emission saving for the time being, since no unambiguous fossil reference situations are available. Validated fossil reference values are often not available and in many situations the fossil reference cannot be determined unambiguously.

Bio-based content:

- No statement on the minimum level of bio-based content is made.
- If a bio-based product is partly bio-based, the claim “bio-based” should be accompanied by a quantification of the bio-based content.

Chain-of-custody models for traceability:

- Physical segregation in which 100% of the product is certified
- Mass balance (type a): the claim no longer follows the physical flow and the claim may be transferred to other biomass products, but not to fossil products
- Mass balance (type b): the claim no longer follows the physical flow and the claim may be transferred to other biomass products and to fossil products
- Mass balance (type c): the claim follows the physical flow as a percentage in mixture.

So in case of bio-based products all mass balance scheme mechanisms are allowed, only book and claim is not allowed.

RSB

The Roundtable on Sustainable Biomaterials (RSB) is an international initiative that brings together farmers, companies, non-governmental organisations, experts, governments, and inter-governmental agencies concerned with ensuring the sustainability of biomaterials production and processing. Originally set up in 2007 to ensure the sustainability of liquid biofuels for transport, the RSB expanded its scope in 2013 to cover biomaterials and subsequently changed the B in its name from Biofuels to Biomaterials. RSB is a multi-stakeholder initiative with its members organized into seven Chambers that represent different sectors of business, civil society, trade unions, government, academia and multi-lateral organizations. The RSB exceeds the requirements in the RED Directive and includes:

- Principle 1: Legality (national and international laws and regulation)

- Principle 2: Planning, monitoring and continuous improvement (transparent and consultative impact assessment, and economic viability)
- Principle 3: Greenhouse gas emissions (Biofuel blend must be 50% better over lifecycle than fossil fuel)
- Principle 4: Human and labour rights (protect workers' and human rights)
- Principle 5: Rural and social development (focus regions of poverty)
- Principle 6: Local food security (direct impacts)
- Principle 7: Conservation (conserve and protect important conservation values, ecosystem services and functions)
- Principle 8: Conserve and protect soil
- Principle 9: Conserve and protect water
- Principle 10: Conserve and protect air
- Principle 11: Use of technology, inputs, management of waste (risks, chemicals, wastes)
- Principle 12: Land rights (respect land rights and land use rights).

The principles and whole certification system are well documented. The RSB website (www.rsb.org) shows that 25 certificates have been issued and that two certification bodies have been approved (July 2015). The certification scheme is complete and very well documented, but it is not relatively little used in practice.

RSB and bio-based products
In March 2013 the Roundtable on Sustainable Biomaterials (RSB) has published an RSB Standard for Certification of Bio-products.

It has the following main features

- Claims on GHG emission reduction of the bio-based product are possible, if a RSB Greenhouse Gas methodology or any LCA methodology in conformance with ISO standard 14040 or the GHG Protocol Standards are applied, and if a significant (10% or more) reduction in lifecycle GHG emission is demonstrated. This claim is voluntary.
- The bio-based content shall be based on an annual average and shall not be less than 25% (by weight). Biochemicals producers and bioproduct manufacturers shall determine the bio-based content of their products based on ASTMD6866, CEN/TS 16137 or any equivalent protocol.

Furthermore, RSB considers the introduction of certificates, which are sold separately to the product (the book-and-claim system) to help manufacturers source sustainable bio-based feedstock even when none may be available in proximity to their manufacturing sites. This could help companies in the early stages of replacing fossil-based products with bio-based alternatives (Williams 2014)[30]. However, this could also mean that products could be sold as bio-based without having bio-based content. This approach is debated in CEN/TC 411,

[30] Williams, M. (2014) RSB approach to certification of bio-based chemicals, Bio-based plastics magazine 2014/04.

resulting in the position that all bio-based products should have bio-based content, and thereby abandoning book-and-claim for bio-based products from their standard.

ISCC

The International Sustainability and Carbon Certification System (ISCC) is governed by the ISCC association. The sustainability requirements exceed the RED requirements and include:

- Principle 1: Biomass shall not be produced on land with high biodiversity value or high carbon stock and not from peat land. High Conservation Value (HCV) areas shall be protected.
- Principle 2: Biomass shall be produced in an environmentally responsible way. This includes the protection of soil, water and air and the application of Good Agricultural Practices.
- Principle 3: Safe working conditions through training and education, use of protective clothing and proper and timely assistance in the event of accidents.
- Principle 4: Biomass production shall not violate human rights, labour rights or land rights. It shall promote responsible labour conditions and workers' health, safety and welfare and shall be based on responsible community relations.

The ISCC website shows more than 12000 certificates (July 2016). ISCC is a truly international certification system with certificate holders in many countries like Czech Republic, Germany, France, USA, UK, the Netherlands, Indonesia, etc. Thirty three certification bodies can perform ISCC certification. Its popularity in many countries shows that the system works well in practise. It could also indicate that its sustainability requirements are more easy to meet than for instance RSB and NTA8080. All documentation can be found on http://www.iscc-system.org/[31]

ISCC and bio-based products

The ISCC PLUS system has been developed for food and feed products as well as for technical/chemical applications (e.g. bioplastics) and other applications in the bioenergy sector (e.g. solid biomass).

Within ISCC PLUS, it is possible to chose between a set of voluntary add-ons that complete the obligatory basic requirements. These add-ons are modules that either apply to the agricultural area or to the whole chain of custody:

- add-on 202-01 "Environmental Management and Biodiversity" and
- add-on 202-02 "Classified Chemicals" apply to the agricultural area, whereas
- add-on 205-01 "GHG Emissions" and
- add-on 205-02 "Consumables of a Production Process" apply to the whole chain of custody.

The use of the add-ons is voluntary and does not underlie the general ISCC PLUS certification. When choosing an add-on, the certification scope will be extended to the add-on chosen. Special provisions are laid down for bioplastics in ISCC PLUS 260-02.

[31] http://www.iscc-system.org/en/certification-process/isccsystemdocuments/iscc-plus/

So far (July 2016) 24 bio-based products have been certified, such as ethylene, propylene, PLA, lactic acid, hemp straw, as well as animal fat, starch, sugar cane and bioethanol.

ISCC does not apply a minimum share of biomass to be used in the bio-based product, but requires reporting the actual share of biomass in the bio-based product.

ISCC PLUS allows both the mass balance and physical segregation approach. The mass balance approach allows producers to allocate the certified sustainable bio-based share to only one or several out of all products. This product cannot be indicated as being bio-based, but a claim like “supporting to responsible sourcing of bio-based materials”. See (ISCC, 2015).

ANNEX B Comparison of NTA8080, RSB and ISCC

The Tables in this Annex present the overview of the differences between the former NTA 8080:2009, the RSB and the ISCC-system as of 2009. They are based on van Dam 2010 and the "Y" in the cells means that the topic is included as a principle or criterion. The appreciation has been added by the author, and needs to be regarded as indicative summary of the performance of the scheme on a certain topic compared to the other schemes.

Table 14: Biodiversity topics included in the certification schemes. Based on (van Dam 2010)

Topic	NTA8080	RSB	ISCC
Primary forests specifically mentioned	-	-	Y
Biodiverse grassland specifically mentioned	Y	Y	Y
New plantings specifically mentioned	Y	Y	Y
Nature prot. areas by relevant authority (nat. level)	Y	Y	Y
Protected areas recognised by international agreements (Ramsar, Kyoto, CBD)	Y	Y	-
Protected areas in lists drawn up by IUCN	Y	Y	-
Protected areas defined by stakeholder process	-	Y	-
Additional criteria	Y	Y	-
Appreciation	**++**	**++**	**+**

Table 15: Identified criteria and indicators for soil quality and quantity included in the certification schemes. Based on (van Dam 2010)

Topic	NTA8080	RSB	ISCC
Records of fertilizer/agrochemical inputs	-	Y	-
Records and monitoring (incl. analysis, translation to management plans	Y	Y	-
Identification of soil types on each site of area	-	-	-
Maps of (fragile) soils are available	-	Y	-
Compliance of relevant laws and regulations	Y	-	-
Indicated parameters for analysis soil quality			
Soil organic carbon	-	-	-
Soil organic matter	Y	Y	-
pH soil	Y	-	-
Nitrogen, phosphor and potassium	Y	-	-
Quality surface residues	-	-	-
Soil suitability for intended crops	-	-	-
Soil salts content	-	-	-
Indicated parameters for analysis soil quantity			
Soil loss in tons/ha/year	Y	-	-
Quantity and use of surface residues	Y	-	-
Info on susceptibility soil to erosion	-	-	-
Info on conformation, slope, land form	-	-	-
Info on wind exposure soil	-	-	-
Field observations on evidence (or not) from erosion or	-	-	-
evidence of practices	-	-	-
Plans and strategies mentioned			
Soil management plan or strategy	-	-	-
Nutrient recycling strategy specifically mentioned	-[a)]	Y	-

Specific strategy or plan to minimise risk erosion	-	Y	Y
Appreciation	**+**	**+**	**-**

[a)] Remark from the author: ash recycling is mentioned in NTA8080.

Table 16: Identified criteria and indicators for water quality and quantity included in the certification schemes. Based on (van Dam 2010)

Topic	NTA8080	RSB EU RED	ISCC
Monitoring of water used for irrigation	-	-	-
Records and monitoring (incl. analysis, translation to management plans)	Y	Y	Y
Compliance with relevant laws and regulations	Y	-	-
Address effects of water use on local resources	-	-	Y
Indicated parameters for analysis water quality			
Temperature	-	-	-
Dissolved oxygen	-	-	-
Nitrogen	-	-	Y
Phosphor	-	-	-
Turbidity	-	-	-
BOD level on/near production unit	Y	-	-
Total suspended solids in mg/l	-	-	-
Agrochemical inputs in input/ha/year	-	-	-
Origin of (irrigation) water	Y	-	-
Indicated parameters for analysis water quantity			
Net water consumed per unit mass of product	-	-	-
Mill water use per ton of FFB	-	-	-
Use of (irrigation) water sources in l/ha/yr	Y	-	-
Data records for irrigation prediction	-	-	-
Plans and strategies mentioned	-	-	-
Water management plan	-	Y	-
Plan or documentation indicating best practices	-	-	-
Plan for minimising subsidence of peat soils	-	Y	-
Appreciation	**+**	**+**	**+**

Table 17: Identification of variety of environmental topics included in the certification schemes. Based on (van Dam 2010)

Topic	NTA8080	RSB	ISCC
Good (farming) practices	y	Y	-
Waste	y	y	-
Air	Y	Y	-
Fire	y	y	-
GMO	-	y	-
Pesticide management	y	y	Y
No invasive species	-	y	-
Hygiene, quality product	-	-	-
Appreciation	**++**	**++**	**+/-**

Table 18: Overview of selected principles on social well-being of workers included in the certification schemes. Based on (van Dam 2010)

Topic	NTA8080	RSB	ISCC
No child labour	Y[a)]	Y	Y
Minimum age (years)	-	Y	-
Freedom from discrimination	Y[a)]	Y	Y
Freedom of labour; no forced labour	Y[a)]	Y	Y
Freedom of association and collective bargaining; freedom to organise and negotiate	Y[a)]	Y	Y
Right of indigenous people explicitly mentioned	Y[a)]	Y	-
Appreciation	**+**	**++**	**+**

[a)] NTA8080 refers directly to the UN ‘Universal Declaration of Human Rights’.

Table 19: Overview of selected principles on well-being of local communities included in the certification schemes. Based on (van Dam 2010)

Topic	NTA8080	RSB	ISCC
Legal and customary rights	Y	Y	Y
Procedures	y	y	-
Proof of ownership	y	y	y
Compensation systems available	y	y	-
Well-being local communities	Y	Y	Y
Contribution towards local economy and activities	y	-	-
Fair and transparent prices available	-	-	-
Compensation for use traditional knowledge	-	-	-
Preference employment of local people	-	-	-
Local procurement services and inputs	-	-	-
Support local education	-	-	-
Safeguarding local food security	-	y	y
No replacement of staple crops	-	y	y
Use of (co-) products does not affect traditional/local use	y	y	-
Participation/communication local people	Y	Y	Y
Procedures or methods established	y	-	y
Complaints and grieving mechanism	-	-	y
Social Impact Assessment in participatory way	Y	Y	-
Existence of social management plan	-	-	
Specific measures to target vulnerable groups	-	y	
Take measures to counteract negative effects	y	-	
Mentioned parameters for SIA are:	Y	Y	-
Access and use rights/land tenure	y	y	-
Physical and economic displacement	y	-	-
Economic livelihoods, working conditions	-	y	-
Job creation and potential loss	-	y	-
Subsistence activities	-	y	-
Cultural and religious values	y	y	-
Gender differences	y	-	-
Health and education facilities	Y	Y	-
Other community values	-	-	-
Appreciation	++	++	+

Table 20: Overall appreciation of the coverage of sustainability topics in NTA8080, RSB EU RED and ISCC Source: own analysis BTG based on van Dam (2010)

Sustainability topics covered	NTA8080	RSB	ISCC
Biodiversity	++	++	+
Soil quality and quantity	+	+	-
Water quality and quantity	+	+	+
Other environmental topics	++	++	+/-
Social well-being workers	+	++	+
Well-being local communities	++	++	+

ANNEX C CEN standards relevant for sustainability of bio-based products

CEN/TC 411

Acknowledging the need for common standards for bio-based products, the European Commission issued mandate M/4921, resulting in a series of standards being developed by CEN/TC 411, with a focus on bio-based products other than food, feed and biomass for energy applications. The standards of CEN/TC 411 "Bio-based products" provide a common basis on the following aspects:

- Common terminology;
- Bio-based content determination;
- Life Cycle Assessment (LCA);
- Sustainability aspects;
- Declaration tools.

Relevant standards include:

- Sustainability criteria for bio-based products (EN 16751:2016)
- Life cycle assessment of bio-based products (EN 16760:2015)
- Overview of methods to determine the bio-based content (NPR-CEN/TR 16721:2014)

Sustainability criteria for bio-based products (EN 16751:2016)

The criteria of EN 16751:2016 can either directly be used by an operator or can be used to qualify proprietary schemes and standards which cover sustainability aspects. By defining a common framework, this European Standard will allow the provision of information on sustainability aspects for the following uses:

- for an operator to assess and manage sustainability aspects of its operation, and to report in a consistent manner;
- for operators in a value chain to exchange and share information with a common framework and understanding.

The Standard contains general requirements, environmental, social and economic principles, criteria and indicators similar to those found in other sustainability schemes i.e.:

- Environmental criteria:
  - Climate protection and air quality
  - Water
  - Soil
  - Biodiversity
  - Energy and material resources
  - Waste
- Social criteria:
  - Labour rights
  - Land use rights and land use change
  - Water use rights

   - Local development
- Economic criteria:
   - Economic sustainability.

All criteria shall be addressed for the biomass production and the standard may also be used for other operations along the bio-based product value chain. However the criteria are mainly reporting obligations, describing the procedures to identify and the measures to minimise the impacts. The standard does not set any minimum requirements. For instance: regarding climate production the criterion is *"The economic operator provides information on how greenhouse gas (GHG) emissions related to their operations are managed.".* The indicators are: *"Describe procedures taken to identify GHG emission sources and/or potential impacts on climate change related to their operations."* and *"Describe measures to minimize GHG emissions"*. The standard gives no minimum GHG emission savings nor an obligation to calculate the GHG emissions. This European Standard cannot be used to make claims that operations or products are sustainable since it does not establish thresholds or limits. This European Standard can however be used for business-to-business (B2B) communication or for developing product specific standards and certification schemes.

Life cycle assessment of bio-based products (EN 16760:2015)
Life cycle assessment (LCA) is a multi-step procedure for calculating the lifetime environmental impact of a product or service. The complete process of LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation. The process is by nature iterative as the quality and completeness of information and its plausibility is constantly being tested. LCI is the life cycle inventory, which is the data collection portion of LCA. LCIA is life cycle impact assessment, the "what does it mean" step. In LCIA, the inventory is analysed for environmental impact.

The newly developed European Standard EN 16760 "*provides guidance and requirements to assess impact over the life cycle of bio-based products*". The standard states that GHG emissions and removals from both fossil and biogenic carbon sources and sinks must be listed in the inventory analysis and should be considered in the impact assessment. It provides descriptions of typical emissions in bio-based product life cycles, such as CO_2 and CH_4 emissions from soil, and recommends guidelines to calculate these emissions (e.g. other EN standards and IPCC guidelines). Later, it introduces two approaches for modelling CO_2 emissions related to biogenic carbon, either including CO_2 sequestration in biomass with negative values and emissions at the end-of-life with positive values, or appointing both a factor zero. Section 5.4.2.2.5 of EN 16760 refers to the consideration of land use change in GHG accounting and states that for ILUC there is currently no agreed scientific method in coherence with the modelling principles of LCA, and that is may only be addressed in the interpretation phase..

ANNEX D Overview of some initiatives relevant for sustainability of bio-based products

Bioeconomy observatory

The Bioeconomy Observatory is an attempt to gather and present in one place vital data about the development of the bioeconomy. It is intended to be a critical resource for policy-makers, business people and other stakeholders designing the policies and investments at national and regional level. The website of the European Bioeconomy Observatory aims to show developments and progress towards making the European Bioeconomy Strategy a reality. Within this framework JRC has among others collected LCA data of a number of bioeconomy products, including bioenergy, food and bio-based products. See Matos et al. (2015).

Green deal for green certificates for bio-based rubber and plastic products

In 2011, the Dutch Rubber and Plastics Association, SABIC and the Dutch Ministry of Economic Affairs signed a Green Deal for the development of green certificates for sustainably produced bio-based feedstock used for bio-based rubber and plastic products. Along with the Association of the Dutch Chemical Industry (VNCI), Plastics Europe Netherlands, the plastic injection moulding company Kellpla and the Netherlands Enterprise Agency (RVO) have developed guidelines for assuring the sustainability of these green certificates. Starting point for the elaboration of the green certificates was to aim at affiliation with recognized international schemes for biofuel sustainability. Some of these schemes have recently expanded their scope to incorporate bio-based products. Furthermore, the Green Deal partners cooperate with the German INRO-initiative, which has the same objective (see next section). In 2014, a number of pilot projects were initiated to test the green deal approach. Companies producing (partly) bio-based polymers and composites are working with certification institutes and certification schemes to determine whether their products could be certified. The results are available on http://greendeal-groencertificaten.nl/..

INRO

The aim of the German INRO *'Initiative for the Sustainable Supply of Raw Materials for the Industrial Use of Biomass'* is to reach an agreement with industrial companies on the voluntary certification of renewable raw materials to the point of their first processing. INRO is not pursuing the installation of its own certification scheme. Instead, the initiative aims at developing comprehensive criteria to assess good practice of existing and future biomass sustainability certification systems. INRO has established a set of sustainability criteria for material use of biomass (INRO, 2013b) and INRO Criteria for good Certification Systems (INRO, 2013a). INRO has assessed a number of existing sustainability certification schemes and has declared (INRO, 2014) that INRO currently recommends the following certification systems: ISCC and ISCC PLUS, RSB, RSPO, Rainforest Alliance (SAN), Bonsucre and RedCert (only in Europe).

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ASTM D6866-12	Standard Test Methods for Determining the Bio-based Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis
CEN/TS 16137:2011	Plastics - Determination of bio-based carbon content.
EN 16575:2014	Bio-based products – Vocabulary
EN 16640:2014	Bio-based products - Determination of the bio based carbon content of products using the radiocarbon method
EN 16751:2016	Bio-based products – Sustainability criteria
EN 16760:2015	Bio-based products – Life Cycle Assessment
EN 16785-1:2015	Bio-based products – bio-based content – part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis
ISO 14040:2006	Environmental management -- Life cycle assessment -- Principles and framework
NTA 8080-1:2015	Sustainably produced biomass for bioenergy and bio-based products – Part 1: Sustainability requirements
NTA 8080-2:2015	Sustainably produced biomass for bioenergy and bio-based products – Part 2: Chain of custody requirements
prEN 16785:2-2015	Bio-based products – Bio-based content – Part 2: determination of the bio-based content using the material balance method

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