Climate effects of the forest-based sector in the European Union

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Abbreviations, measurement units and conversions

Unit	Description	Corresponds to (conversions used in this study)
m^3ob	Cubic meter over bark. Mostly used for the volume of growing stock in the forest	0.83 m^3ub
m^3ub	Cubic meter under bark. Mostly used for roundwood timber	1.20 m^3ob 0.25 tC
m^3swe	Cubic meter solid wood equivalent. Used to relate forest products and bioenergy to volume of sourced wood material	1 m^3ub
T	Ton	1000 kg
Ha	Hectare. Common area measure for forests	0.01 km^2
M	Millions	
tCO_2e	Ton carbon dioxide equivalents	1/3.67 tC
tC	Ton carbon	3.67 tCO_2
EU27+3	Geographic scope of this study – the 27 member states of the European Union, plus United Kingdom, Norway and Switzerland	

Executive Summary

The European forests and the forest-based sector provide integrated solutions to the global climate challenge on a very large scale. The overall and positive climate effect is estimated at -806 million tons of carbon dioxide equivalents annually. This corresponds to c. 20% of all fossil emissions in the European Union.

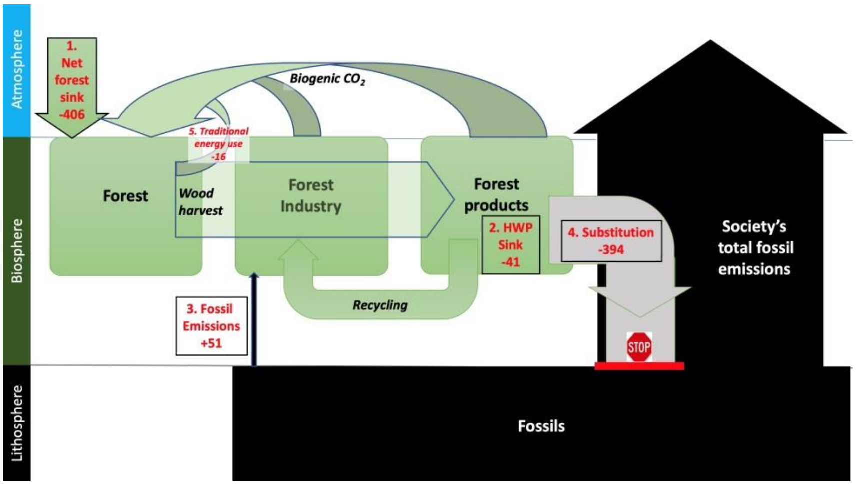
The overall climate effect is calculated as a sum of

- net sink (increased carbon storage) in forests (-406 Mt CO_2e/yr) resp. forest products (-41 Mt CO_2e/yr) for a total of -447 Mt CO_2e/yr
- fossil emissions caused in the forest sector value chain: +51 Mt CO_2e/yr
- prevented fossil emissions by substituting fossil-based materials and fossil energy: industrial products -394; traditional energy -16; for a total of -410 Mt CO_2e/yr

The key to appreciating the large contributions of forests and the forest-based sector is the perspective of an integrated and circular bioeconomy. CO_2 is removed from the atmosphere in very large quantities and stored in growing forests. The carbon eventually circulates back into the atmosphere to close the loop. Part of this carbon is stored, for a longer or shorter period, in a variety of forest products before re-entering the natural biogenic carbon cycle.

Forest products have a very low climate footprint and moreover they reduce demand for products and energy that are based on fossil fuels. This prevention of fossil emissions, or substitution effect, is well known but has not previously been visualized and quantified at the European level. Existing climate reporting and climate policies are not structured to highlight such cross-sectorial effects. By providing a complete analysis of the climate effects of the European forest-based sector, this study aims to support the policy dialogue towards effective climate action.

Viewing the forest-based sector as a circular bioeconomy may open up debate on how to reinforce sinks and carbon storage in forests, while at the same time enhancing how forest products and bioenergy provide climate solutions. European forest resources continue to expand both in standing volume and annual growth, which may offer further potentials.



The five climate effects (Mt CO_2e/yr) of the forest-based sector in EU27+3 countries as defined in this study. The total effect is -806 Mt CO_2e in 2018, corresponding to c.20% of EU fossil emissions.

Introduction

Can forestry and forest products provide solutions at scale for the global climate challenge, alongside contributions to economic and sustainable development?

Over the past 150 years, we have turned away from land as the base of the economy and instead increasingly used fossil deposits to accelerate supply of goods and services to a growing world population. This has fuelled growth, created wealth and expanded welfare, but at the cost of a huge impact on the global climate. Man-made global climate change has now evolved into a major contemporary challenge for humanity. Turning around the current climate trajectory is paramount for managing risks to society. This must be done in ways acceptable to human wellbeing and at the same time suitable for political discourses.

Greenhouse gas emissions from fossil fuel combustion is the dominating cause behind man-made global climate change (IPCC, 2014). Awareness is rising rapidly of unwanted consequences on all dimensions of sustainable development (Steffen et al., 2018). At the same time, cheap energy from fossil fuels continues to offer pathways to economic development and poverty reduction for countries in transition and helps maintain prosperity in other regions. It has proven difficult to navigate the political dilemma of handling the global climate amidst other, local and pressing development priorities.

International arrangements such as the UNFCCC with its Paris Agreement (UNFCCC, 2015) as well as European Union strategies and legislation (European Commission, 2020) call for decisive and effective climate action that make significant and durable reductions of man-made climate change. However, finding and leveraging solutions that are simultaneously positive for development and the global climate is a big ask. Such solutions would have to, *inter alia,*

- rely on renewable energy,
- deliver (near) fossil-free products,
- provide for the local economy,
- offer attractive investment opportunities,
- operate on a scale significant enough to directly or indirectly impact the global climate

and at the same time ensure that the natural environment, human rights and ethics are not compromised.

The forest-based sector has the potential to simultaneously deliver on all of these points.

The current study quantifies to which extent the European forest-based sector mitigates climate change by storing away carbon and at the same time contributes to a fossil-free future by providing alternatives to fossil-based products. Earlier studies suggest that the sector has a great potential, as exemplified by studies from Sweden (Holmgren, 2019) and on the European level (Nabuurs et al., 2017). The study extends the model established by Holmgren and Kolar (2019) to 30 European countries (EU27 + UK, Norway and Switzerland, expressed as “EU27+3” in the below).

It provides a snapshot of the European forests and the forest-based sector and how its different segments relate to the global climate. The argument is made that the forest-based sector must be considered as a whole, thereby cutting across some traditional structures in climate policy. When, as the study argues, the forest-based sector is viewed as a circular bioeconomy, it becomes obvious that large-scale solutions to the climate challenge are already at hand.

The report does not analyse in detail how existing or potential policy instruments may support or hinder continued realization of forests and the forest-based sector's climate effect. Neither does it venture into scenario developments. The purpose has been to provide a clear and communicable perspective of the sector, built on existing facts and transparent analyses.

The study was commissioned by the Confederation of European Paper Industries (Cepi).

Overview of the European forest-based sector

The forest-based sector – a circular bioeconomy

Forests and the atmosphere are engaged in a constant exchange of carbon. Through photosynthesis, vegetation absorbs carbon dioxide from the air and converts it to plant tissue, including cellulose. The cycle is completed as vegetation eventually decomposes or burns, returning the carbon to the atmosphere. Globally, this biogenic carbon cycle turns around as much as 220 Gt CO_2 per year (net primary production on land, most in forests), or about six times our current fossil emissions (Haberl et al., 2007).

When wood is used for a variety of purposes, the natural biogenic carbon cycle is extended by storing carbon for a longer or shorter time in forest products. Eventually almost all carbon embedded in these products will also oxidize and return to the atmosphere, thereby rejoining the natural biogenic carbon cycle. In 2018 about 6 bn m^3 of industrial roundwood and wood fuels were harvested globally (FAO, 2019), corresponding to about 5 Gt CO_2e, or about 2% of the global net primary production of biomass. An illustration of the forest-based sector as part of the biogenic carbon cycle would therefore be that a small proportion of the carbon flow is diverted and temporarily stored in forest products (Figure 1)

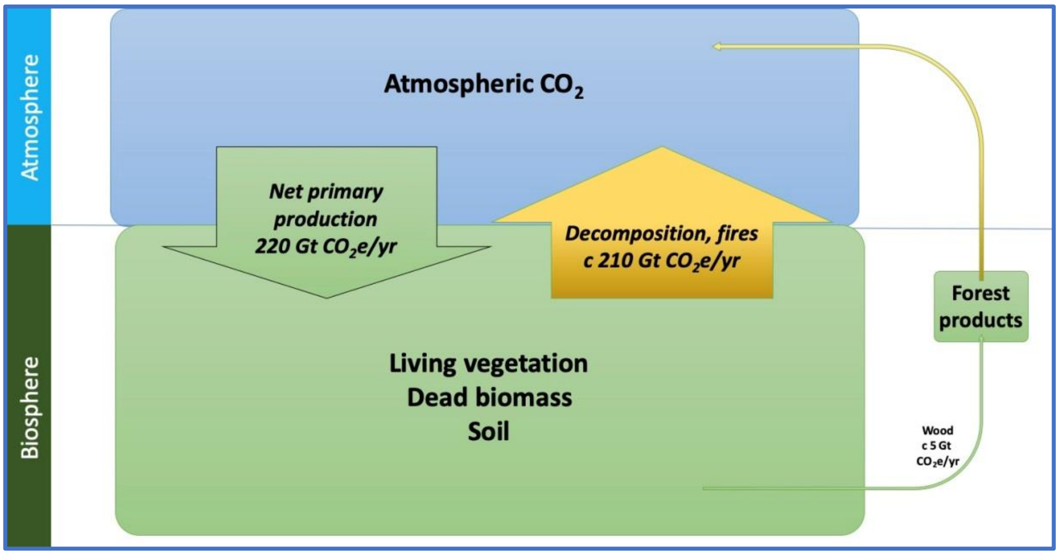


Figure 1. Global biogenic carbon cycle on land related to the forest-based sector. Forest products "borrow" 2% of the carbon flow for temporary storage. Numbers consider 6 Gt CO_2e/yr net biomass gain as reported by IPCC (FAO, 2019; Haberl et al., 2007; IPCC, 2014).

European (EU27+3) forests cover 174 million ha or about 4.5% of the world total. EU27+3 forests cover 37% of the countries' land area, compared with 30% forest cover globally. The EU27+3 forestry sector applies more intensive forest management than the global average with an annual wood harvest of 516 million m^3 (2018), or 9% of the world total (FAO, 2019, 2016).

Legal requirements, economic development, investments in reforestation, expansion of forests and forest management has resulted in an increasing forest carbon storage as only part of the European forest growth is harvested and used in forest products and for bioenergy.

As forests are harvested sustainably, the EU27+3 forest-based sector can be illustrated as a circular bioeconomy as per Figure 2. This perspective is the starting point for the current analysis of the climate effects of the European forest-based sector.

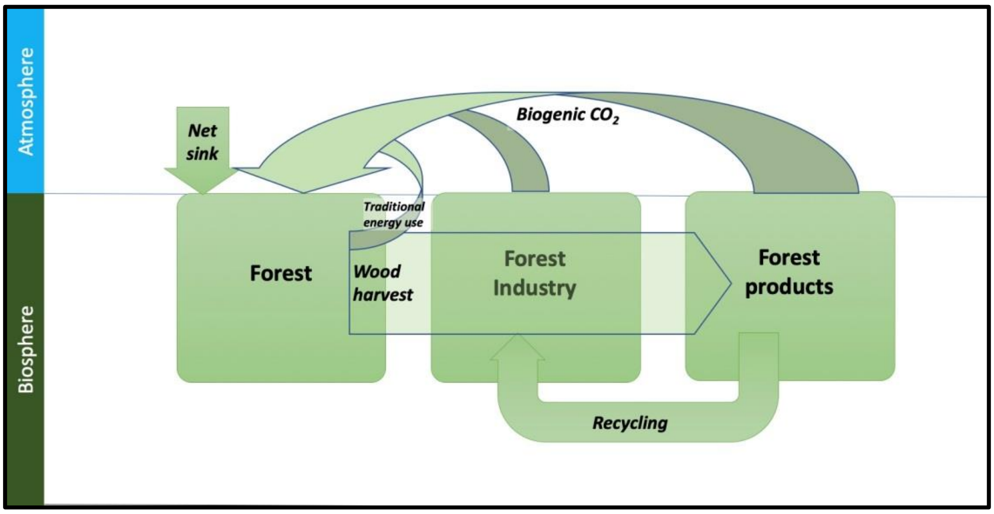


Figure 2. Principal biogenic carbon flows of the forest-based sector, reflecting the situation in Europe with a net sink (net increase of forest carbon stock) and a high level of recycling of forest products. Carbon is returned to the atmosphere both during industrial processing and after end-use of products. Note that dedicated bioenergy power & heat plants are considered as part of the industry system.

Forest management, growth and harvest

For consistency, this study considers all forests in the EU27+3 countries, that is, including forests that for a variety of reasons are currently not considered for wood harvests. This approach corresponds with the reporting of forest and land use to the UNFCCC, and also avoids discrepancies between countries as to how forest management categories are reported to different international processes. In other words, all forests are considered to be subject to forest management, acknowledging that this includes areas set aside for conservation. Regardless of the specific management objectives, however, it is clear that all forests as such play an important role vis-à-vis the global climate.

European forests (EU27+3) covered about 174 Mha in 2015 or just under 40% of the total land area. This is 8% more than in 1990, i.e., the forest has expanded by 0.13 million km^2 or twice the combined size of Belgium and the Netherlands.

From 1990 to 2015 the growing stock increased by almost 40% to 28 billion m^3 stemwood over bark (23 billion m^3ub) (FAO, 2016), corresponding to an increase in average stocking from 125 to 160 m^3ob/ha. A study by Nabuurs et al. (2013) concluded that the rapid increase of standing volumes in European forests over past decades may begin to slow down due to biomass saturation of the forest system both as stands are older and as losses to pests, wind and fire increasingly balance out the growth. This could indicate the beginning of gradually lower levels and potentials of carbon net sinks in the forest.

Based on 2015 data, forest stemwood growth in all EU27+3 forests is about 1 billion m^3ob/year, or 816 million m^3ub/year. Of this, about 65% is harvested, 25% is left in the forest and adds to an increasing volume of living trees, and the remaining 10% of volume growth is balanced by trees dying in the forest. In 2018 the harvest consisted of 516 million m^{3}ub of industrial roundwood of which 121 million m^{3}ub of wood fuel according to FAO (2020) (Table 1).

Table 1. Key data on forests and forest management. Note that the table compares and converts data from different official sources which may cause deviations. Based on officially reported numbers and estimates FAO (2020, 2016). Forest data refer to 2015, harvest data to 2018.

	Forest area	Forest % of land area	Growing stock	Forest growth	Harvest	Wood fuel % of harvest	Harvest % of growth
	Mha	%	Mm^{3}ub	Mm^{3}ub/yr	Mm^{3}ub/yr	%	%
EU27+3	**174**	38	**23 255**	**816**	**516**	23	63

Forest products and bioenergy

The annual (2018) harvest of about 516 million m^{3}ub wood in EU27+3 countries is processed and used in a variety of ways. For the purpose of this study, uses of the wood harvest is divided according to flows identified in Figure 2, i.e.:

1. Wood, fibre-based and bioenergy products delivered to the market from the forest industry, including use of forest-derived biomass in dedicated power & heat plants;
2. Wood used as bioenergy within forest industry processes;
3. Wood used for traditional bioenergy purposes, mostly for residential heating. This category does not enter the forest industry value chain.

<u>1. Solid wood, fibre-based and bioenergy products delivered to the market</u>

This study aggregate products into three broad categories (Table 2). Solid wood products amounted to 181 million m^3 in 2018 and fibre-based products to 107 million tons. These numbers are directly available by country from official statistics (Cepi, 2019; FAO, 2020).

However, it is not straightforward to determine the level of marketed bioenergy. This is partly because bioenergy statistics (Bioenergy Europe, 2020) generally categorize information so that biomass quantities sourced from the forest cannot easily be separated out. In addition, statistics from forest industries focus more on the consumption of energy than on marketing of surplus bioenergy – although these quantities appear to be on the rise. And further, statistics on the proportion of sawmill by-products that end up as marketed bioenergy outside of the forest sector is not complete. Marketed bioenergy products have therefore been estimated as a combination of chemical forest industry statistics, estimates for sawmills and derivations from available bioenergy statistics and studies (Bioenergy Europe, 2020; Mantau, 2015; UNECE, 2019).

Table 2 Categories of marketed forest products and forest-sourced bioenergy considered in this study

Category	Quantity delivered 2018 for EU27+3 countries	Comment

Solid wood products	181 million m^3	The sum of sawn wood and wood-based panels as reported in FAO (2020)
Fibre-based products	107 million tons (c. 150 million tons m^3swe)	Products based on wood pulp. Quantity refers to total of "paper products" in (FAO, 2020)
Marketed forest-sourced bioenergy	c. 320 TWh (c. 120 million tons m^3swe)	Based on Bioenergy Europe (2020) and Cepi (2019). Calculated as production of heat and electricity from solid biomass, reduced by consumption in forest industry. Liquid biofuels not included due to lack of comprehensive statistics

2. Wood used as bioenergy in forest industry processes

Bioenergy fills an important role in forest industry processes as a fossil-free energy source extracted as a by-product of the raw material. As a result, the European pulp and paper industry sources on average 60% of its energy supply from its own biomass, reaching as high as 96% in Sweden (Cepi, 2019). As indicated in Figure 2., this means that a significant proportion of the harvested biomass is returned to the atmosphere (and then back to the forest) by the forest industry processes and not turned into marketed products. These biogenic emissions do not influence the climate effect of the forest-based sector. However, they are important to include in model calculations so as to account for all carbon fluxes in the circular system.

From Cepi (2019) data it was estimated that the pulp and paper industry used bioenergy at a level of 272 TWh in 2018, corresponding to c. 100 million m^3swe. Sawmills also use considerable amounts of biomass for energy. Informal data obtained suggest that about 0.2 m^3 wood equivalents are used as energy for each delivered m^3 of sawn wood, which would equal c. 25 million m^3swe at EU27+3 level. While this is an approximation, it should be noted that biogenic emissions are considered climate-neutral (as they return to the forest) and do not affect the overall climate effect calculations. The forest industry processes thereby use an estimated 100 + 25 = c. 125 million m^3swe as wood energy.

3. Wood used for traditional bioenergy purposes

For EU27+3 countries, 24% of overall wood harvest is reported as wood fuel, corresponding to 121 million m^3ub in 2018 (FAO, 2020). However, harvested wood fuel is used both for residential heating, for large-scale power & heat generation, as well as in industrial processes. Conversely, it is worth noting that the harvested wood fuel comprises less than 40% of total wood energy use as the majority of wood energy in Europe comes from secondary sources throughout the value chain, including from recycled products (UNECE, 2019).

The share of harvested wood fuel used for traditional bioenergy was calculated based on UNECE (2019) using "residential heating" as the proxy. About 70%, or 84 million m^3ub in 2018, of the harvested wood fuel appears to be used for residential heating, the balance divided mainly between power & heat plants and bioenergy use in the industry.

Recycling

Recycled paper products, for which statistics are readily available, are included in the study. In 2018, 48.8 million tons of recycled paper was utilized by the industry, as reported to Cepi, representing a recovery rate of 72% (Cepi, 2019). Extending the statistics to all countries in this study brings the number to 52 million tons (c. 80 million m^3swe). Recycling of solid wood is not highlighted in this study, except in the designation of substitution effects for the life cycle and end use of solid wood products.

Material flows in the European forest-based sector

With the inputs established above, approximate annual material flows in the European forest-based circular bioeconomy can be illustrated as in Figure 3. This reflects the level of detail considered in this study. For an earlier, more detailed description of material flows, please refer to Mantau (2015). A summary of estimated product output by country in 2018 is provided in Table 3.

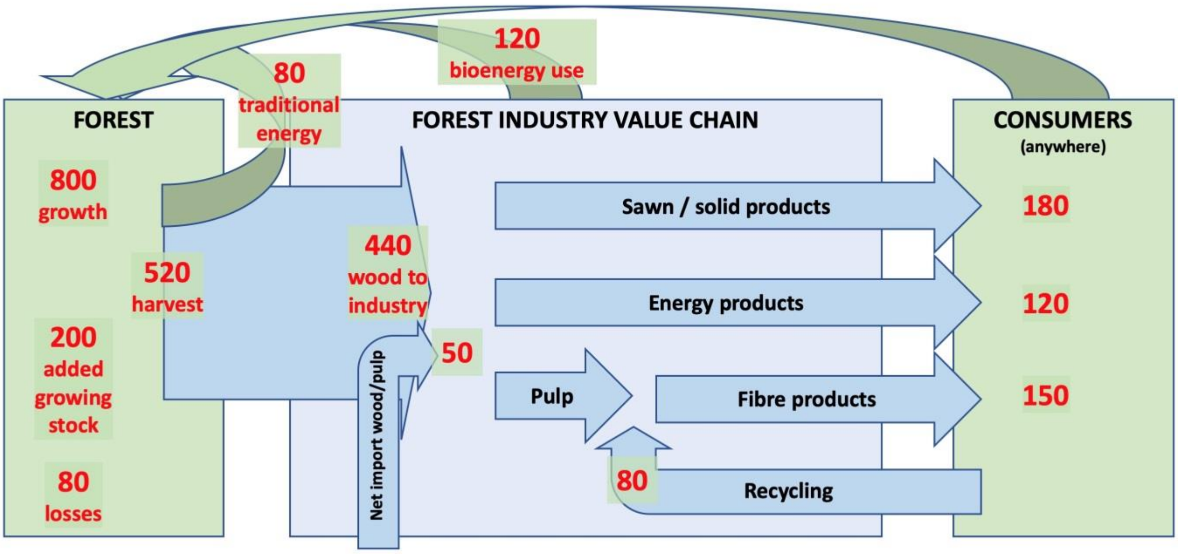


Figure 3. Approximate material flows in 2018 for EU27+3 forest-based sector as considered in this report. All numbers express million m^3swe. Forest volumes refers to stemwood. Does not include effects of material disposals or changes in product stock.

Table 3. Forest products output. Data and estimates for year 2018, based on sources and assumptions explained in the main text

Country	Traditional bioenergy use (estimate)	Sawn wood	Wood-based panels	Fibre-based products	Use of recovered paper	Marketed bioenergy (estimate)
	Mm^3	Mm^3	Mm^3	Mt	Mt	TWh
EU27+3	85	116	65	107	52	324

The forest-based sector and the international climate arrangements

Forests have a prominent role in the international climate discourse. UNFCCC has a strong focus on negative climate effects of deforestation (UNFCCC, 2020a). National Inventory Reports (NIRs) to the convention under the Kyoto Protocol (UNFCCC, 2020b) include anthropogenic changes in forest carbon pools according to the detailed IPCC reporting guidelines on "Land Use, Land Use Change and Forests" (LULUCF) (IPCC, 2006). IPCCs latest global assessment of climate change highlights the role of forests in the climate system and estimates that the forestry and land use (change) sector (FOLU) represents 11% of the overall negative human impact on the global climate (IPCC, 2014, p.5), or, in other words, 11% of the problem through net losses of biomass.

The same picture is conveyed by the special IPCC report on Climate Change and Land (IPCC, 2019). Here the overall land use contribution is estimated at 23% of total anthropogenic climate impact of which, again, forestry and land use change contribute about half (IPCC, 2019, p.9), indicating a loss of biomass (-5.8 Gt CO_2e per year) caused by humans. However, IPCC also makes clear that the overall net global change of biomass on land is clearly positive (+6 Gt CO_2e per year), a net absorption of about 15% of our global fossil emissions. This contradiction is possible as IPCC considers forest lands not subject to harvest as not part of the anthropogenic regime – the biomass growth on these lands is instead assessed as "natural response" (IPCC, 2019, p8 para A3.3). The overall gain of biomass globally contains components of large losses through tropical deforestation but even larger gains in temperate and boreal regions where sustainable forest management is prominent. It appears therefore that forest management that over time leads to higher carbon storage over time is not reflected as a climate action in IPCCs top-level messages, and that the picture of the forestry sector as part of the problem may not be entirely accurate.

IPCCs global estimates are not directly comparable with NIRs where the LULUCF methodology is used to report on changes in forest carbon pools, which for the European countries mean that changes in the entire forest is considered. The picture of the forestry sector in these countries then becomes overall positive, as explored further in the below.

The current study goes beyond the UNFCCC/IPCC delineation of the forestry and land use sector to also estimate climate effects of harvested wood as part of the forestry sector. Carbon storage in "Harvested Wood Products" (HWP) is already included and specified in national inventory reports, but the prevention of fossil emissions through material or energy substitution is not made explicit in those same reports. Consequently, while constructing a higher proportion of buildings in wood will reduce emissions in other sectors, it is not possible to extract this effect from current official statistics and attribute the positive effect to the forest-based sector. Better visualization of the forest-based sector's overall effects may be significant when designing climate policy interventions.

The perspective here is a forest-based sector as part of a circular bioeconomy. Analyzing climate effects and related interactions throughout this cycle provides a more complete picture of the sector's impact and potential. This approach cuts across sectoral structures as defined in current greenhouse gas inventory reporting methodologies where the forest is characterized as a carbon storage separate from other sectors. Enriching the perspective of the forestry sector's climate effect in this way may also enhance synergies between climate action and achieving wider sustainable development goals.

Material and Methods

Data sources

The study is based on publicly available statistics, in most cases official statistics provided by countries (Table 4). In some parts, internal private sector production data have been used.

Table 4. Publicly available data sources used in the study

Subject area	Source	Comment
Forests and forest management	Global Forest Resources Assessment 2015 (FAO, 2016)	Original source of nationally reported statistics, replicated by UNECE, Forest Europe, World Bank. Latest data from 2015.
Wood harvesting and forest products	FAOSTAT section of forestry production and trade (FAO, 2020)	These nationally reported statistics are jointly collected by FAO, Eurostat, Forest Europe, UNECE and ITTO. Latest data from 2018
Industry production with environmental data	Cepi statistics (Cepi, 2019)	Reports from Cepi member countries.
Climate impact	National Inventory Reports (NIRs) to the UNFCCC (European Environment Angency, 2020; UNFCCC, 2020b)	NIR reports for 2019 were used, reporting LULUCF data for 2017
Bioenergy	Bioenergy Europe (2020) UNECE (2019)	Statistical reports on bioenergy. Bioenergy Europe not explicitly specifying forest sources
Basic country data	World Bank (2020)	World Bank open data

Model for estimating the sector's climate effect

Up front in the UNFCCC convention text (United Nations, 1992) there is a division on how to handle greenhouse gases, either go for the "anthropogenic emissions by sources" or to enhance "removals by sinks". Ever since, the forestry sector is placed in the latter category under the legal framing "conservation and enhancement, as appropriate, of sinks and reservoirs of (..) greenhouse gases" whereas fossil emissions in other sectors are handled under the first category under the call to "control, reduce or prevent anthropogenic emissions of greenhouse gases". Structures of following negotiation tracks, reporting formats and policy measures can be traced back to this early division. By contrast, the model presented in this study straddles the basic UNFCCC categories by suggesting that the forestry sector includes both effects on fossil emissions as well as effects on carbon sinks and storage, and that these need to be considered as a whole.

Following the above logic of a circular bioeconomy (Figure 2), the following climate effects are considered present in the forest-based sector:

1. Net carbon sink in the forest as a result of photosynthetic growth minus natural losses and removals through harvest (corresponding to Forest Land, reported as category 4.A in LULUCF);
2. Net carbon sink in harvested wood products (corresponding to Harvested Wood Products (HWP) reported as category 4.G in LULUCF);
3. Fossil emissions from direct or indirect use of fossil fuels in forest industry value chains (as per established reporting of fossil emissions (WRI & WBCSD, 2020), normally included in the EU Emissions Trading System);
4. Prevented fossil emissions via forest products that replace products with a higher fossil emission footprint, also known as substitution (currently not included in reporting or policies, see section below).
5. Prevented fossil emissions from the use of traditional bioenergy, typically for heating of houses. (currently not included in reporting or policies)

Taken together, these factors illustrate the complete climate effect of the forest-based sector (Figure 4).

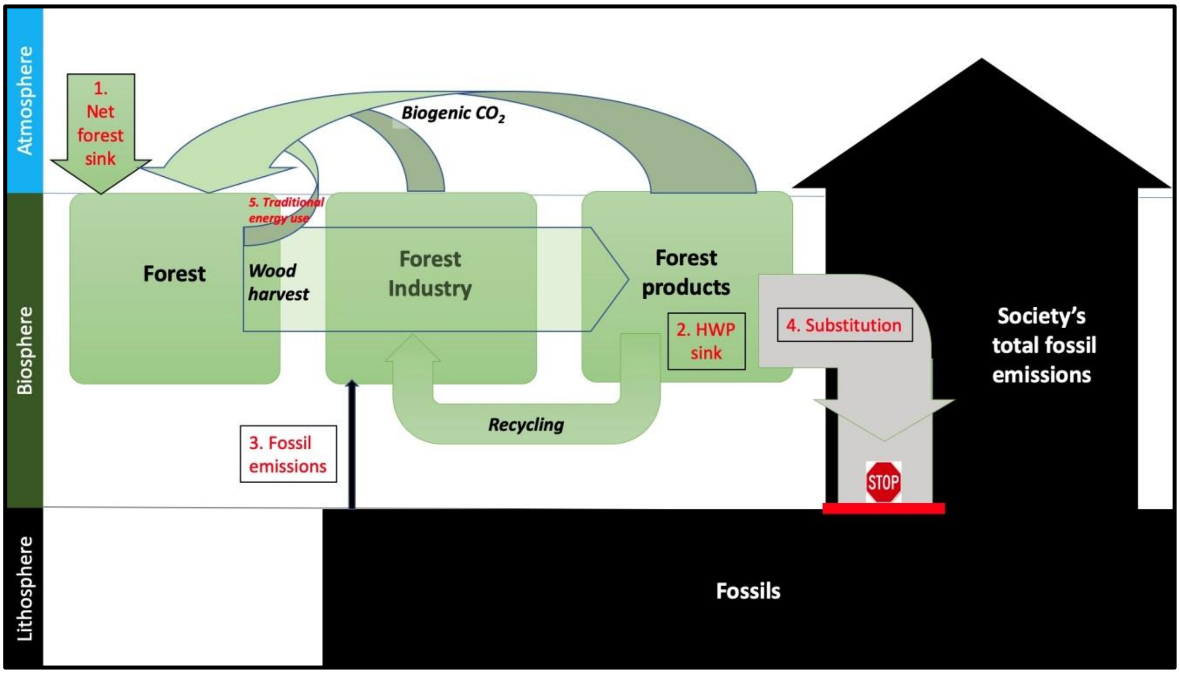


Figure 4. Model of overall climate effects by the forest-based sector, extended to view relation to society's fossil emissions. Climate effects occur in five ways marked with red text and described in the main text. This paper estimates these effects for EU27+3 countries.

Preventing fossil emissions through substitution

Preventing fossil emissions of fossil-dependent materials and fossil energy with alternatives that have a smaller climate footprint is referred to as substitution. Substitution effects have been alluded to throughout the UNFCCC process (e.g. IPCC, 1990) but are not made explicit in official climate reporting (IPCC, 2006; UNFCCC, 2020b), partly as they typically cut across the sector structure applied in climate reporting. While substitution effects are theoretically and implicitly covered in these reports, it may be therefore impossible to derive these effects from official statistics – for example how much an increasing share of wood in construction reduces emissions from cement and steel production as well as emissions in the construction or maintenance processes. This study aims to visualize the existing substitution effect as part of the forest-based sector's overall climate effect.

The recent IPCC report on Climate Change and Land refers to substitution by wood in their analysis of mitigation potentials. The potential is put at a relatively modest level (0.25-1 $GtCO_2e$/yr globally) and refers only to solid wood products replacing cement and steel (IPCC, 2019, p.48). The mitigation potential of Bioenergy with Carbon Capture and Storage (BECCS) is considered much higher at 0.40-11.30 $GtCO_2e$/yr, out of which "up to several $GtCO_2e$/yr" (p.25) relates to the bioenergy as such leading to "avoiding combustion of fossil energy" (p.575), i.e. a substitution effect although not referred to with this wording in the Land report. It is also important to note that:

- These are estimated potentially <u>additional</u> mitigation through substitution by wood and bioenergy. That is, the level of substitution/prevention effects already in place through delivery of forest products are taken for granted from a climate change mitigation perspective. By contrast, this study highlights current substitution effects and does not project further potentials into the future.
- Large scale bioenergy expansion for mitigation, including as part of BECCS systems, is treated with caution, although the positive integrated example of the Swedish forestry sector is well noted (IPCC, 2019 p.582)
- Forest fibre products based on wood pulp are not considered in the Climate Change and Land report.

Overall, it is notable that substitution effects derived from the land-based sector is given a prominent role in the IPCC projections, alongside enhancing carbon sinks and conserving storage in the biosphere.

The wide ranges of estimated potentials from substitution reflect uncertainties, both regarding the possible scales of future deployment and also regarding the substitution factors stating to what extent a given quantity of bio-based materials/energy prevent fossil emissions. For this report the scale is known from high-quality statistics of actual delivery of forest products in the EU27+3 countries. As to the substitution factors, calculations have been based on available research.

Holmgren and Kolar (2019) and Leskinen et al. (2018) provide recent literature reviews of substitution factors for forest products in European countries and arrive at similar conclusions. This report uses the findings of Holmgren and Kolar (2019) as a starting point. From this review, it is clear that differences in boundary conditions between earlier studies must be handled. In particular, studies that have incorporated carbon storage changes in the forest and/or fossil emissions in the value chain in their factor estimates do not fit well with the current calculation model, where these factors are considered separately. Holmgren and Kolar (2019) make this distinction and include only those studies that estimate the substitution factor of the product as such.

Moreover, it is important to determine whether the full life of the material is considered, for example, recycling of packaging can result in several rounds of substitution before end-use as bioenergy – then providing energy substitution. The factors by Holmgren and Kolar (2019) were determined with this multiple cycles specification, although underlying studies had treated recycling in different ways.

Further, the generalization of substitution factors for the total volume of forest-based products can be challenged as the underlying studies often apply a more specific use of a narrow set of products in life-cycle assessments that may not be entirely suitable for extrapolation to the full range of products and uses. For this reason, factors were generalized conservatively for a small set of broad product categories and should not be regarded as precise measures. At the same time, specifying average substitution factors for broad product categories is an active choice to avoid getting lost in detail.

Finally, substitution factors will change over time. More efficient use of bio-based materials, new innovations for more climate-smart products and enhanced recycling will lead towards higher substitution factors. At the same time, reduced climate footprints of fossil-based materials will lead towards lower substitution factors. This report considers substitution factors as they are currently understood and estimated, for assessment of overall substitution effects as of today.

From the above it is clear that substitution factors come with a set of uncertainties, partly as they have not been subject to the same standardization and compartmentalization process as the calculation and reporting of emissions *per se*. However, given the significance and potential of substitution as an effective climate action that prevent fossil emissions, it appears important to provide conservative estimates that visualize the current performance of the forest-based sector. This is also important to support policy designs that take into account the substitution effect as part of the sector's climate performance, thereby avoiding potentially counterproductive approaches that, e.g., are limited to storing carbon in forests.

The following substitution factors were applied in this report, building on Holmgren and Kolar (2019) with additional considerations for the EU27+3 countries (Table 5)

Table 5. Substitution factors used in this report (tons prevented fossil emissions per ton of bio-based carbon in product category, tC/tC), building on Holmgren and Kolar (2019)

Product category	**Factor in Holmgren & Kolar (2019)**	**Factor applied in this report**	**Comment**
Solid wood products (sawn wood and panels), with end-use as bioenergy	1.5	1.5	Substitution varies considerably between different uses of solid wood. Given that end-use for energy is included, this should be considered a conservative estimate.
Fibre products, with recycling and end-use as bioenergy	0.7	1	This factor was set conservatively by Holmgren and Kolar (2019) to only reflect end-use of the material as bioenergy as knowledge on fibre products' substitution is limited. Some new and expanding wood fibre products (eg textiles) appear to have a high substitution factor (Leskinen et al., 2018) who also applied a factor 1.2 for fibre products overall. In addition, the EU27+3 forestry sector includes more of multiple recycling of fibre products compared with the Swedish situation dominated by exports of products based on virgin fibre. To account for innovative fibre products and a high degree of recycling, a higher factor is applied here compared with the previous study.
Large-scale bioenergy (including industrial generation in eg CHP plants, and by-products of pulp production)	0.7	0.6	Bioenergy conversion efficiency is very high in Sweden where the original factor was applied, resulting in a relatively high substitution factor. For the EU27+3 countries, a slightly lower rate is assumed, considering eg some co-firing of pellets at lower conversion rates in electricity power plants.
Traditional bioenergy	not considered	0.2	Large quantities of wood are used in EU27+3 countries as traditional bioenergy for eg (partial) heating of houses. Energy conversion rates, heating efficiency or substitution factors were not investigated but are assumed to be at a much lower level than for industrial scale bioenergy.

Calculations and Results

The section includes findings for the five components of the climate effect model (Figure 4):

1. Net carbon sink in the forest as a result of photosynthetic growth minus natural losses and removals through harvest;
2. Net carbon sink in harvested wood products (HWP) as defined by IPCC reporting guidelines;
3. Fossil emissions from direct or indirect use of fossil fuels in forest industry value chains;
4. Prevented fossil emissions (substitution) through the marketing of forest products that replace products with a higher emission footprint;
5. Prevented fossil emissions through use of traditional bioenergy.

This is followed by a summary of the forest-based sector climate effect and elaboration on the impacts of trade flows.

Net carbon sink in the forest and HWP (components 1 & 2)

The effect of these components can be extracted directly from National Inventory Reports (NIRs) to the UNFCCC (European Environment Angency, 2020; UNFCCC, 2020b) as all EU27+3 countries are obliged to report annually under the Kyoto protocol and according to IPCC guidelines, including for the LULUCF sector (IPCC, 2006). This means that there is a high degree of synergy between country data. At the same time, quality in underlying data may vary considerably between countries, particularly depending on the status and ambition of national forest inventory systems (Tomppo et al., 2010). Further, the application of IPCC guidelines has evolved over time, which means that NIRs from different years may not be directly comparable. For this report, data was extracted from 2019 editions of NIRs, containing data for year 2017 (Table 7). Data used include:

- Total change in all forest lands carbon pools – living biomass, dead wood, litter, mineral soils and organic soils (corresponding to LULUCF category 4.A)
- Changes in the Harvested Wood Products pool (HWP, LULUCF category 4.G)

Fossil emissions (component 3)

The forest-based sector is a significant source of fossil emissions, although levels have decreased dramatically, particularly in industrial processes. On average, 60% of energy supply in pulp and paper mills are today sourced from bioenergy. In addition, procured electricity has an increasing proportion of renewable sources. Input goods can come with significant embedded fossil emissions but were not included in this study due to incomplete statistics. In addition to industrial processes, transportation of raw material and products are significant sources of fossil emissions for the sector. Table 6 summarizes the fossil emissions from the sector and how numbers were calculated. Table 7 includes estimated country-level emissions.

Table 6. Overall fossil emissions from EU27+3 forestry sector and method applied to determine country-level data

Emission Category	EU27+3 fossil emissions 2018, Mt CO_2e	Estimation method / comment
Industrial processes: Pulp and Paper with chemical by-products	33	By country according to Cepi statistics, estimated for countries with no data reported (Cepi, 2019)
Industry processes: Sawn wood and panels	4	Based on informally obtained data: 0,02 t CO_2e/m^3 product
Industry processes: Bioenergy	None additional	Emissions in forest industries accounted for above. Heat, power & CHP plants have negligible fossil emissions.
Transport: Supply of roundwood including harvest operations	9	Based on average numbers for Sweden (Björheden, 2019): 0.0139 t CO_2e/m^3
Transport: Products to customers	6	Solid wood products and pulp&paper products only. Based on informally obtained data: 0.03 tCO_2e/t
Input goods	Not included	Not consistently reported. Also depends on product category and system boundary for the analysis.
Total	**51**	

Prevented fossil emissions through substitution (components 4 & 5)

Substitution factors used in this report for four broad product categories were defined above:

- Solid wood products – 1.5 tC/tC
- Fibre-based products – 1.0 tC/tC
- Large-scale bioenergy – 0.6 tC/tC
- Traditional bioenergy – 0.2 tC/tC

These factors are applied only to marketed/consumed products. That is, bioenergy used internally as energy supply to the industry processes does not generate any substitution effect, cf Figure 4. The total substitution effect for EU27+3 countries was estimated at 410 $MtCO_2e$ for 2018. Country-wise results are found in Table 7.

- For solid wood products the substitution effect was calculated as 1.5 tC/tC * 0,25 tC/t wood * 181 Mt wood products * 3,67 tCO_2/tC = <u>249 $MtCO_2e$</u>

- For fibre products, recycling must be considered so as to avoid double counting of substitution effects as the substitution factor is defined to include all recycling phases of the material, including end-use as bioenergy. This means that each fibre should only be counted once for substitution effects. This is done by assigning substitution only to the fraction of new fibres that enter the value chain. The recycling ratio is 49% (52 Mt usage of recycled fibres / 107 Mt total paper products), meaning that the ratio of new fibres entering the value chain in 100-49 = 51%. A substitution effect is therefore assigned to 51% of the total production volume resulting in an overall substitution effect of 0.51 * 1.0 tC/tC * 0.37 tC/t product * 107 Mt fibre products * 3.67 tCO_2/tC = 74 Mt CO_2e. The same ratio is applied to each country in the calculation.

- For industrial scale bioenergy the overall substitution effect was calculated as 0.6 tC/tC * 324 TWh bioenergy / 10 TWh/Mt woodC * 3,67 tCO_2/tC = 71 Mt CO_2e
- Traditional bioenergy was above considered to be sourced from 70% of harvested wood fuel. The substitution effect was calculated as 0.7 * 0.2 tC/tC * 0.25 tC/m3 wood * 121 Mm3 wood * 3.67 tCO_2/tC = 16 MtCO_2e

Total climate effect

The five climate effects (Figure 4) taken together adds up to a total climate effect of -806 Mt CO_2e per year for the EU27+3 countries. This is the sum of -447 Mt CO_2e increased carbon storage in forests and HWP, +51 Mt CO_2e fossil emissions by the sector and -410 Mt CO_2e of prevented fossil emissions through substitution (Table 7).

Table 7. Climate effect of the forest-based sector in EU27+3 in year 2018

	Forest carbon sink LULUCF 4.A	Harvested wood products (HWP) sink LULUCF 4.G	Fossil emissions	Prevention of fossil emissions through substitution					Total climate effect
				Solid wood products	Fibre-based products	Industrial bioenergy	Traditional bioenergy	Total substi-tution	
	Mt CO_2e	Mt CO_2e	Mt CO_2e	Mt CO_2e	Mt CO_2e	Mt CO_2e	Mt CO_2e	Mt CO_2e	Mt CO_2e
EU27+3	**-406**	**-41**	**51**	**-249**	**-74**	**-71**	**-16**	**-410**	**-806**

Discussion

Significance of results

Looking at the forest-based sector across conventional UNFCCC reporting structures reveals a much higher positive climate effect than if the forest is assessed in isolation as a set of carbon pools. The study builds a case that the forest-based sector should be regarded as a circular bioeconomy and that it needs to be analysed as one integrated system.

The total assessed climate effect of -806 MtCO_2e in one year corresponds to 20% of all fossil emissions in the European Union. About half is due to increased carbon storage in forests and forest products – this part is clearly visible in existing climate reporting. The other half is due to prevented fossil emissions through substitution – this part is not visible in climate reporting but is necessary to understand the sector's overall impact.

It is not the purpose of this study to make any policy prescriptions. However, an obvious conclusion from the analysis is that the LULUCF framework only addresses one part of climate effects of the forest-based sector – the storage of carbon in the forest. Limiting the policy discourse on forests and climate to LULUCF therefore risks arriving at inaccurate conclusions for at least three possible reasons:

- Projections of continued high levels of net carbon sinks in the forest may not materialize as risks of storms, pests or fire will increase, possibly more if large tracts of forests are left with little active management for wood production;

- Putting emphasis on carbon storage in the forests, but none on preventing fossil emissions through substitution, may lead to less reductions of fossil emissions than possible and necessary;

- Undervaluing the positive feedback loop by which demand for timber puts a value on the standing forest, thereby disincentivizing long-term investment and active management which in turn lead to more stable and increasing sinks and storage.

Instead, it would appear relevant to have the forest-based sector relate to all three main components of EU climate policy: LULUCF; ES and ETS.

The model is applied to the European situation with overall actively managed forests with a long-term build-up of forest carbon as well as an advanced forest industry infrastructure. Applying the model in other regions where, e.g., large-scale deforestation processes are present or value chains less developed will likely lead to completely different conclusions.

Model considerations

Data availability is good for all countries for most parameters. However, the climate challenge and evolution of the sector may require new datasets that are currently not established. In this study, some problems occurred for the classification of wood-based bioenergy, emissions data except for internal processes of the chemical forest industry, and more specific knowledge on and distribution of substitution effects. Sector organisations at national and European level may want to review how statistics are collected and reported.

Model results in this study are a snapshot of one year, i.e. a static study. Expectations are sometimes expressed for a dynamic analysis. In particular, there is a certain demand for scenarios that show results of alternative treatments of the forest over long time periods. Further, projections are wanted the substitution effects are expected to change over time, both as forest products and their use will be even more effective, but also as the fossil-based alternatives will become more resource efficient. However, while some aspects of forestry can be modelled with some precision far into the future, it is not likely that assumptions on product innovation (wood-based as well as alternatives), markets, or policies can be projected with the same level of accuracy. Given the current state of knowledge on several of these factors, complex scenario developments of the current model cannot be recommended.

The applied model does not highlight the role and effect of trade. Instead, the focus lies on territorial carbon pools in the forest, and territorial production of forest products and bioenergy. At the same time, EU is a large net importer of roundwood, pellets and pulp and the links to the forests that source the raw material is important from a sustainability perspective but imported raw materials do not affect the model outcome as such. At the other end of the value chain, EU is a net exporter of forest products, but it has no implication for the model where the products are used, as the end-use in almost all cases anyway returns the carbon to the atmosphere, which will then exchange some of its CO_2 with the forest. Overall, therefore, trade is obviusly important for realizing the circular bioeconomy and climate opportunities, but the model is not sensitive to the source or destination of the wood carbon.

Suggested continued analyses

There are many areas where more knowledge would be helpful for enhancing the forest-based sector's contribution to the global climate challenge, such as:

- Reviewing opportunities for using more biomass in innovative supply chains. The current build-up of biomass in the European forests will become less and less stable as a carbon storage. At the same time, the opportunities for expanding or developing new value chains are not obvious as new forest resources often are in different areas or of different types than conventional industrial wood. Moreover, land ownership may be highly fragmented.

- Investment opportunities in forest industry and large-scale efficient bioenergy production. Coming generations of fibre products (such as textiles), chemicals/biofuels and construction material may offer new opportunities within existing industry structures. Making the best of investments in large-scale power, heating or cooling, however, will require entire new infrastructures at municipial or city scales.

- The sector still has large fossil emissions. Despite huge reductions in industrial processes over the past decades, transportation of wood and products remains as a major climate challenge for the sector. Smarter logistics systems combined with new transport technology and biofuels may offer solutions.

- In line with above opportunities, continued work to understand the potential and efficacy of bio-based products in substituting fossil-based ones is necessary. Standards that lay a ground for broad policies for replacing fossil-based materials, products and energy are needed. It is unlikely that politically endorsed standards and reporting protocols related to UNFCCC and IPCC will go in this direction. Instead, stakeholders of the forest-based sector may be in a better position to take the lead to promote and deliver the circular bioeconomy.

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