SUOMEN ILMASTOPANEELI
The Finnish Climate Change Panel

CLIMATE IMPACTS OF FOREST USE AND CARBON SINK DEVELOPMENT

Jyri Seppälä, Markku Kanninen, Timo Vesala, Jussi Uusivuori, Tuomo Kalliokoski, Jussi Lintunen, Laura Saikku, Riitta Korhonen, Anna Repo

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SUMMARY

Finnish forests fix more carbon dioxide from the atmosphere than they release into it, thereby acting as carbon sinks and cooling the climate. Research and scenario runs strongly suggest that Finnish forests will remain as notable carbon sinks in the next decades.

Results of simulation models show that increasing wood utilization will decrease forest carbon sinks and forest carbon stocks in Finland for several decades, compared to a situation in which utilization is not increased.

The results show that with wood utilization corresponding the current levels of harvest will cause more climate benefits even in the medium-term (50-100 years), compared to the increased harvesting scenario. The loss of carbon sinks in forests is greater than the substitution benefits gained from the use of wood in the short and even medium terms. However, the use of wood will produce more climate benefits in the long term compared to the use of fossil fuels, if the growth conditions for forestry land will not be degenerated.

Climate change mitigation in the short-term (10–30 years) requires the rapid restriction of fossil fuel emissions, to prevent global mean temperature rising above two degrees deemed dangerous. In light of this, it is questionable to greatly increase wood utilization activities that releases carbon as carbon dioxide into the atmosphere in the short-term. Carbon content of wood products is currently released rapidly into the atmosphere, apart from wood utilized as construction materials.

Current research does not clearly assert how short- and medium-term increases in carbon dioxide emissions from forest utilization to the atmosphere, and climate benefits gained in the long-term, relate to each other in climate change mitigation.

The use of wood can be best argued on the basis of climate reasons, when a wood product can replace a product with high greenhouse gas emissions (with the whole product chain taken into account), and its carbon content can be stored for a long time, and finally, it is used for energy purposes. The climate benefits, even in the short-term, can be reached by using wood residues for energy production instead of using round wood and if rapidly decomposing logging slash and thinning materials smaller than industrial wood are directed into energy utilization. Furthermore, climate benefits in the short-term can be gained from afforesting both wasteland and fields left outside of agricultural utilization.

In the future, the substitution benefits from wood products and forest energy in relation to alternative products and energies changes with a society's aspiration towards low carbon levels and the technological advancement of new products. Climate benefits from forest energy are the most difficult to achieve in a low-carbon future. On the other hand, the utilization of new wood products (e.g. nanopulp) can achieve considerable climate substitution benefits in the future, for example when replacing steel.

If forest utilization and the management and reporting practices of carbon sinks continue in the current manner in future climate agreements, model examinations consistently show that the planned additional usage of woodchips for energy production as formulated in the Finnish energy and climate strategy does not endanger the realization of political climate goals, at least in the short term. However, these model examinations have shortcomings, which are apparent in the increasing uncertainty of carbon sink development forecasts as the examinations progress further from the present time.

Research suggests that taking the climate impact of carbon solely into account does not guarantee the optimal results for forest management and utilization in relation to the climate. However, it is currently too early to say how the total albedo and aerosol effects of forests will affect the climate. On the other hand,

these and the emissions originating from particulates created through wood burning and black carbon must be considered when discussing the climate impact of forests and forest utilization.

Current climate agreement rules do not greatly encourage the increase of forest carbon sinks. The recompensing of the system should be developed in this regard, but it should not lead to reduced willingness to decrease fossil fuel emissions.

1. INTRODUCTION

Evaluating the climate impacts of products and energy manufactured from forest biomass has long been based on the belief that an equivalent amount of carbon dioxide is fixed into new vegetation as is released during biomass utilization. The climate effects of wood utilization have been considered zero when forestland is not destroyed and when the carbon dioxide released during wood utilization is sequestered into new biomass. This rule of thumb concerning the carbon neutrality of forest raw materials has internationally been used for a long time when assessing the climate impacts of wood utilization. A century is the typical time frame for such assessments.

Several scientific studies have recently questioned the belief that wood utilization has no impact on the climate. The opinion has arisen that wood utilization should not be increased for climate reasons. Additionally, individual greenhouse gas emissions coefficients should be evaluated for the various wood fractions (stumps, branches, etc.). However, decreasing wood utilization in a country such as Finland has also been suggested to lead to short-term carbon sink growth, while greater long-term climate benefits are attainable with intensive forest utilization and silviculture, as otherwise the carbon sink will weaken. Forest-derived wood products can substitute for products that would otherwise cause greater greenhouse gas emissions.

An inventory calculation, agreed upon during the climate agreement (UNFCCC), can be used to follow the carbon balance of growing stock and forestland in relation to the realized emissions and sinks. The calculation method has been developed in the IPCC frame, but parties of the climate agreement and Kyoto protocol have decided on how widely to apply the method and on the obligations connected to it. The temporal development of the carbon sinks of various countries is fundamental in the long run in relation to impact on the climate. The Durban climate conference decided that each party having ratified the second obligation period of Kyoto has a separately defined country-specific forest sink comparison level. However, the agreed upon rules do not really reward the increasing of a sink from its comparison level when pursuing climate obligations. This does not encourage sink growth. However, this conflicts with the idea that increasing sinks can be used to gain climate benefits.

This abovementioned obscure condition is also apparent in the international climate debate. It can lead to a situation, where forest biomass utilization and the rules for calculating the general climate impact of the land use sector are altered in the international emissions inventory. The rules for carbon sinks could be redefined in new climate agreements. In the worst-case scenario these changes can be based on insufficient considerations. Due to the importance of the matter, the Finnish climate panel saw fit to provide its own input to the conversation.

Combining the impressions of the scientific community into the following questions became the goal of this report:

- which types of forest utilization accrue the largest climate benefits when considering the development of forest carbon sinks and the emission reductions gained through forest products and forest energy.
- how the accounting of the climate impacts of forest utilization should be changed in international climate agreements.

The aim of the work has been to recognize the consensus areas and differences in opinion prevailing in the scientific community, along with their justifications. This review has been used to formulate recommendations for the most central messages aimed at decision-makers along with a plan for the analyses required by a follow-up project. All other forest utilization effects apart from climate impacts have been ruled out of this assessment.

To complete the project the climate panel sent a questionnaire to 36 Finnish researchers, and received 24 responses in return. Results of the expert questionnaire concerning the climate impacts of forest utilization are presented in a separate report (Saikku 2015). A seminar was also arranged for the respondents. Further, the project conducted a literature review on the following themes: What do forest models tell us of the future development of Finnish forest carbon sinks? (Kalliokoski and Repo 2015) and Economics, climate change, and forests (Lintunen and Uusivuori 2015). Results gained from the professional questionnaire, seminar, and literature review have been utilized in the compilation of this report and the literature reviews have also been published separately in the reports of the Finnish Climate Change Panel (4/2015). The Climate Change Panel has previously compiled a report on the topic (Pingoud et al. 2013), which this current report significantly broadens based on the new far-reaching examinations.

2. FOREST CARBON BALANCE AND CARBON SINK DEVELOPMENT

2.1 Concepts and accounting principles

Finland and other nations that have ratified the climate agreement (UNFCCC) assess the forest carbon stock changes in forest biomass, dead wood, and soil on a yearly basis, as according to the inventory calculation rules of the agreement. This also applies to reporting on the “land use, land use change, and forestry (LULUCF)” sector in the second commitment period of the Kyoto protocol. Forest emissions in this agreement imply the greenhouse gases released from either the soil or vegetation. Carbon dioxide (CO2) is the single most important greenhouse gas in the LULUCF sector. Forestland methane (CH4) and nitrogen dioxide (i.e. nitrous oxide or laughing gas; N20) emissions are additionally reported.

Yearly change estimates for tree biomass and carbon balance of the soil and dead tree material form the basis for the forest emissions and sinks calculations in the Finnish greenhouse gas emissions inventory. Carbon balance calculations for tree biomass in Finland are based on both the national forest inventory and total removal statistics. Total removal consists of the cutting yield (= the commercial roundwood used by the forest industry or bound for export, along with the wood used by one-family housing and rental or portable circular sawing), stemwood sections left in a forest during harvest (forest waste wood) or because of natural mortality. Total removal statistics are based on the forest industry’s reports on wood utilization, a fuel wood usage questionnaire, and an estimate of natural mortality. Tree carbon balance is calculated by subtracting the yearly total removal (harvests and natural mortality) from yearly stand growth. The resulting net growth is converted into carbon dioxide. The calculation therefore considers tree removal as an immediate emission into the atmosphere (Lehtonen 2009).

Current inventory calculations separately take into account the carbon stocks of harvested trees that end up as wood products. Carbon in wood products is stored for their life cycle, after which it is released into the atmosphere either through combustion or decomposition. Calculations based on the Kyoto protocol consider the yearly net effect of carbon released from or stored by wood products. This net effect is calculated as carbon dioxide. The carbon release and stocks of wood products production from previous years has also been included.

Mineral and organic soil are considered separately in the soil carbon balance estimation during greenhouse gas inventory. The Yasso model is used to estimate the carbon stock changes in forest mineral soils. Experimental follow-up data, forest litter production coefficients, and biomass modeling are used to estimate the carbon storage changes of organic soils. Current calculations also include the effects of logging residues on soil carbon balance changes. Forestland carbon balance estimation also includes land use change and the effects of forest fires. The calculation rules are presented in the national report for greenhouse gas emissions (Tilastokeskus 2015a).

Forest greenhouse gas balance implies the net results of the forest sector in the greenhouse gas inventories. This net result depicts the yearly difference in forest-released greenhouse gas emissions and forest-sequestered carbon, expressed in a carbon dioxide equivalent value. A negative net result implies that forests have a climate cooling effect at the annual level. Carbon dioxide, CH4, and N20 emissions released from the soil are included in the greenhouse gas inventory calculations. Nitrous oxide emissions are formed following organic soil decomposition and fertilization. Methane is released from water-saturated peatlands. Only human-induced emissions and carbon flows, e.g. those produced through forestry, are included in the reporting. The carbon sequestration, and methane and nitrous oxide emissions from natural peatlands are not considered.

The size of carbon storage fixed to forests and soil and its development is essential from a climate perspective. Forests can act as carbon sinks or sources depending on whether they fix or release carbon dioxide or methane. The carbon stock increases when forests act as carbon sinks. Carbon sources are processes and activities that cause carbon dioxide or methane emissions. Carbon sinks are processes, activities, or mechanisms that remove these emissions (United Nations 1992).

A greenhouse gas inventory describes the yearly carbon flux, i.e. exchange, of carbon sequestration and release. This exchange also details how much the carbon stock changes. A positive flux decreases the carbon stock, while a negative one increases it. The carbon stock is formed from tree biomass, dead wood, and soil-bound carbon. The scientific community studying biogeochemical cycles uses the terms NEE (net ecosystem exchange) and NBE (net biome exchange). The NEE refers to the CO2 flux between the forest and atmosphere. This flux is formed through growth and soil decomposition. The NBE expresses total change, which also considers harvests and natural disturbances that remove carbon (NBE = NEE + harvest + disturbances). Forest fires in particular are a form of disturbance.

2.2 Development and current status of carbon sinks in Finland and globally

Finnish forests have long been utilized for human gain. Considerable amounts of wood were used in Finland as early as the preindustrial era for heating, cooking, building, and slash-and-burn. The wood required for tar burning and iron works increased forest utilization, which accelerated with the development of the timber and pulp industries, particularly during the 1870s. Stabilization of private land ownership and legislation restricting forest utilization promoted the birth of a more sustainable forest industry during the early decades of the 20th century.

National forest inventory in Finland began in 1921. Since then the state of forests has been systematically followed, initially using periodical inventory, and using continuous inventory from the 1960s onwards. Assessments of the state of Finnish forests dating to before the 1920s are based on individual studies or observations.

Growing stock quantities are estimated to have decreased strongly in Finland during the 19th century, due to unsustainable forestry. Growing stock quantity is estimated to have been at its minimum level around the turn of the 20th century, after which it has steadily increased (Fig. 1a and 1b). Forest growth and total removal have increased even more considerably (Fig. 1b and 1c). Finnish forest growth is currently ca. twice as large as at the start of the 20th century. Forest volume has simultaneously grown from 1500 million cubic meters to 2300 million cubic meters (Fig. 2), despite forest area remaining nearly unchangeable (Luke 2015). The difference in minimum and maximum forest area was only ca. 2% during 1951–2013.

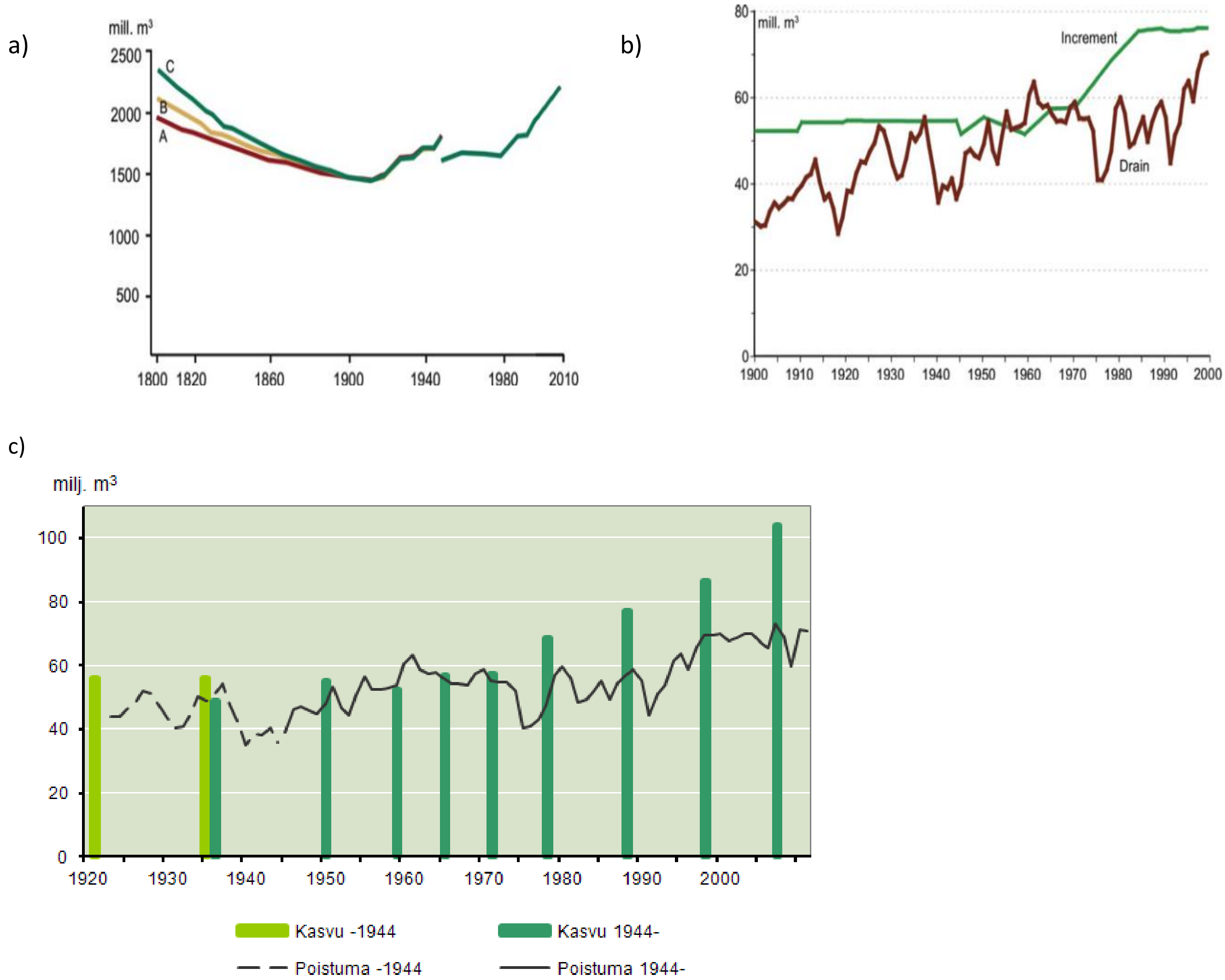


Fig. 1. **a)** Growing stock development (millions m3) in Finnish forests during 1800–2008 (Palo and Lehto 2012). Estimates from the beginning of this time period contain great uncertainty (Myllyntaus et al. 1988, Metsätilastollinen vuosikirja 2010), which is why three alternative scenarios are presented (A–C). **b)** Yearly increment and drain (total removal) (million m3 year-1) of Finnish forests based on national forest inventory and other estimates during 1900–2000 (Palo and Lehto 2012). **c)** Tree development and total removal (million m3) during 1920–2013 (Luke 2015). In addition to harvest accrual, total removal also includes harvest residues, stemwood, and naturally formed dead wood left in the forests. (Kasvu = Growth, Poistuma = Removal)

Forest carbon sink estimation includes removals, land use changes, tree growth and the effects of soil on carbon balance changes. More in-depth assessments of the development of Finnish forest carbon sinks have been made since 1990. These have been made according to the inventory calculation rules of the climate agreement (UNFCCC) (Table 1). Although no accurate estimates of forest net emissions exist for the time period between the turn of the century and 1990, based on Fig. 1c it is possible to see that on average Finnish forests as a whole have been a very small carbon sink during 1922–1972, and occasionally even a carbon source. The emissions balance situation has also been weakened by wide-scale peatland draining after the wars. Draining reached its peak in 1969 (Sarkkola et al. 2009). On the other hand, peatland draining has improved current forest growth and led to a decrease in peatland methane emissions. The yearly forest carbon sink has been distinctly greater during the last 40 years than during 1922–1972.

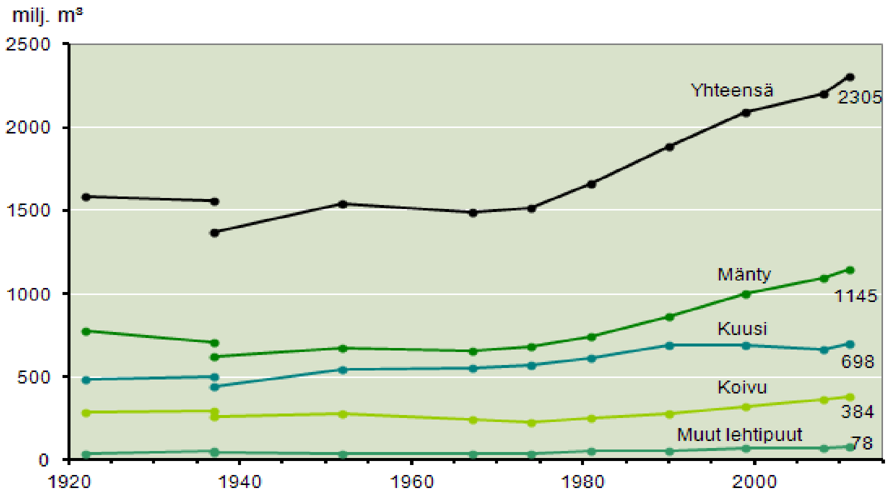


Fig. 2. Forest volume development in Finland during 1935–2013 (Luke 2015). Yhteensä = Total, Mänty = Scots pine, Kuusi = Norway spruce, Koivu = Birch, Muut lehtipuut = Other broadleaves.

The forest carbon sinks of Finland and most industrialized nations have grown during recent decades (UNFCCC 2015). Sinks within the EU have been growing over the last four or five decades. However, the situation in Europe has previously been different, as forests have been converted to agricultural fields, mainly before the 1700s. The forests of several European countries became carbon sinks between 1830 and 1910, following the development of agriculture and forestry, wood politics, and economics, along with the politics governing afforestation and conservation (Kauppi et al. 2006). During recent years sink growth within the EU has decreased, which is considered the first sign that forest sinks are becoming saturated (Nabuurs et al. 2013).

The total sink for all of the EU is estimated to have averaged ca. 435 MT CO2 eq/a during 1990–2012. This equates to nearly 10% of the total emissions produced by the EU during 2010 (Nabuurs et al. 2015). The carbon sink of Finnish forests has averaged 34 Mt CO2 per year during 2010–2013, while the greenhouse gas emissions excluding the LULUCF sector during this time have been 74–61 Mt CO2 eq/a (Tilastokeskus 2015a).

Large losses of forest area due to the conversion of forests to agriculture occurred during 1750–1920 in the United States, and carbon release from forests to the atmosphere grew steadily during this period, peaking ca. around the 1920s (Milner et al. 2014). Carbon emissions are estimated to have been 700 Tg C/a (=268 Mt CO2/a) at this point. However, the forests became carbon sinks as early as 1955, and current carbon balance has stabilized to approximately -200 Tg C/a (Miner et al. 2015, see Fig. 15). The carbon balance of Chinese forests has also developed in a positive direction. On the other hand, Canadian forests no longer function as carbon sinks, but as a source of carbon to the atmosphere (UNFCCC 2015). This is particularly due to insect damage, forest fires, and regeneration obligations coming into force as late as the 1990s (Environment Canada 2015).

Table 1. CO_2 emissions (positive values) and sinks (negative values) of Finnish forests according to the LULUCF inventory (Mt CO_2 eq) (Tilastokeskus 2015).

	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Forest land, total	**-20,4**	**-19,6**	**-26,4**	**-31,8**	**-33**	**-37,8**	**-41,9**	**-32,8**	**-35,5**	**-50,5**	**-34,1**	**-32,9**	**-35**	**-26,4**
Biomass, mineral soils	-16,8	-10,7	-12,1	-17,5	-19	-23,1	-26,5	-19,5	-22,3	-34,6	-20,6	-19,3	-20,2	-12,9
Biomass, organic soils	-11	-12,5	-15,1	-16,5	-16,8	-17,3	-18	-16,6	-15,8	-18,2	-15,5	-15,3	-15,5	-14
DOM+SOM2, mineral soils	-7,8	-9,6	-10,6	-8,6	-8	-8,2	-8,3	-7,2	-7,5	-8	-7,5	-7,5	-8,5	-8,4
DOM+SOM2, organic soils	12,6	10,6	8,9	8,5	8,4	8,5	8,5	8,2	7,9	8,1	7,4	7,2	7,2	6,8
N fertilisation	0,02	0	0,01	0,01	0,01	0,01	0,01	0,01	0,03	0,02	0,02	0,02	0,01	0,01
Biomass burning	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Drained forest land (CH4- ja N20)	2,6	2,6	2,5	2,3	2,4	2,3	2,4	2,3	2,2	2,2	2,1	2,0	2,0	2,1
Harvested wood products	**-4,3**	**-6,1**	**-8,2**	**-6,8**	**-7,2**	**-3,4**	**-6,2**	**-6,9**	**-3,1**	**-0,2**	**-3,9**	**-3,9**	**-3,4**	**-4,4**

DOM= dead organic matter, SOM= soil organic matter

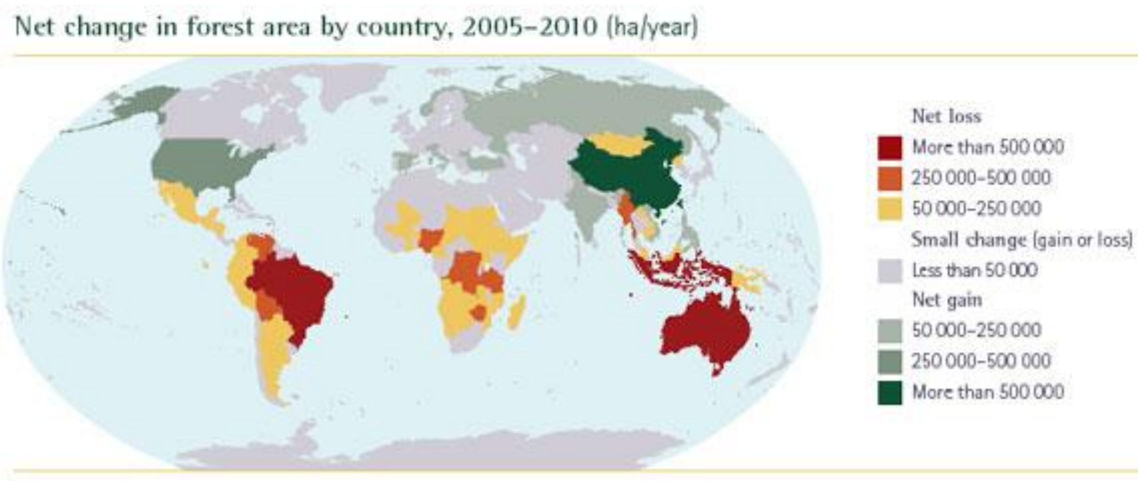


Fig. 3. Net change in forest area, 2005–2010 (hectares/year) (FAO 2010).

Tropical forests in particular have functioned as carbon sources during the past decades (Fig. 3). If another land use form replaces forests, the carbon stock diminishes significantly. Tropical forests have been destroyed to make way for agricultural fields and livestock. Deforestation is still a prominent issue, despite its decreasing importance during recent years. Global forest resource assessments (FAO 2012) showed deforestation to have decreased to 13 million hectares per year by the 2000s from 16 million hectares per year during the 1990s (Fig. 3). Deforestation and forest degradation are estimated to currently cause slightly less than 10% of all human-induced greenhouse gas emissions (van der Werf et al. 2009, IPPC 2014).

2.3 Future projections of carbon sink development

National forest inventory data and models describing forest development have been used to simulate Finnish forest development (MELA, SIMA, EFISCEN). Forest resource models and inventory data have also been combined with economic models depicting wood utilization (SF-GTM, FinFEP). Studies and scenario runs clearly show that Finnish forests will remain significant carbon sinks over the next few decades (Ekholm et al. 2015, EFSOSII 2011, Kallio et al. 2013, Kallio et al. 2014, Kellomäki et al. 2008, Packalen et al. 2015, Sievänen et al. 2014, Verkerk and Schelhaas 2015). The current age class distribution of Finnish forests is a central explanatory factor, which will support growing stock volume growth in upcoming decades. Forest draining, nitrogen deposits, increased atmospheric carbon concentration, and raised temperatures in part additionally explain this accelerating forest growth.

The information about the relationships between increased harvests and forest sink development obtained from models varies greatly depending on e.g. what climate change effects are accounted for in forest growth projections. The Low Carbon Finland –analysis (Kallio et al. 2014), based on the MELA model, notes that Finnish forest carbon sinks will increase significantly during the upcoming decades. This assuming that climate change (as defined by SRES A1B) will considerably increase forest growth, despite woodchip utilization increasing to 25 TWh, as according to the energy and climate political strategy, and the fiber and timber utilization of the forest industry increasing by 20%. On the other hand, Ekholm et al. (2015) suggest that a 15% increase in harvesting from current levels by 2030 would keep the forest carbon sink at its current level or slightly decrease it, if the growth-inducing effect of climate change is not considered. They based their analysis on the scenario calculations in the FinFEP model (Laturi et al. 2015).

Forest disturbances are projected to grow due to climate change, which may reduce the carbon sink from its current level already in the short-term, if wood utilization concurrently increases greatly. Studies simultaneously modeling the effects of climate change on forest growth and disturbances has not been conducted in Finland to a great degree. In addition, the greatest differences/uncertainties/shortages in the forest carbon balance development assessments of various studies are related not only to demand factors, but also to change scenarios concerning growth conditions (temperature, precipitation, nitrogen deposit, soil nutrient balance), the growth responses of these variables, and the environmental responses of soil carbon stocks (Kalliokoski and Repo 2015).

Forest harvesting greatly influences the size of a carbon sink. Modeling studies show that increasing wood utilization decreases the forest carbon sinks and stocks for decades, at least when compared to a situation where utilization has not increased (see section 4.1., Fig. 12). This is also valid in a situation where the forest carbon sink and carbon stock will be increasing

The abovementioned also indicates that the future development of Finnish carbon sinks is and has been reliant on the amount of imported wood. During 2000–2007 imported wood made up ca. 27% of total raw wood amounts. During the last years this has been ca. 15% (Peltola 2014, Luke 2015).

One potential climate change –induced threat is that soil decomposition processes will strengthen more rapidly than tree growth in the future as climate change progresses. As a result, Finnish forests could become carbon sources, if the development of global greenhouse gas emissions cannot be restricted close to the target path of the two-degree goal set (Wieder et al. 2005).

3. TIME SPANS AND VIEWPOINTS

3.1 Climate policy and climate change

The baseline of current international climate politics is to limit the rise in average global temperature to two degrees. However, there is no scientific evidence proving that a two-degree change is a clear threshold in terms of climate change control, beyond which the consequences caused by climate change would be dangerous (Victor and Kennel 2014). This level is more a political decision in a situation where global temperature will continue rising in any case due to already generated greenhouse gases.

Various greenhouse gases have different lifetimes in the atmosphere (Fig. 4). They also have varying abilities to prevent the heat from solar radiation escaping back to space. The lifetime of greenhouse gases in the atmosphere together with their absorption properties create a warming effect, which is defined as radiative forcing (measured in W/m2 units). For example, carbon dioxide has a long lifetime in the atmosphere, which increases its radiative forcing in relation to shorter-lived greenhouse gases such as methane.

Carbon dioxide emissions currently cause the majority of the directly human-induced radiative forcing heating on the climate (IPCC 2014). Carbon dioxide emissions, occurring mainly through the burning of fossil fuels, have disturbed the natural carbon cycle. This has caused the accumulation of excess carbon dioxide compared to preindustrial times. The concentrations of other greenhouse gases have also grown in the atmosphere. The warming effect caused by greenhouse gases will continue for several millennia even if their anthropogenic emissions were reduced to zero today.

In this current situation a rapid restriction of greenhouse gases entering the atmosphere in the short-term is necessary to ensure climate change control. Greenhouse gas concentrations in the atmosphere cannot be allowed to grow too high and cause a global temperature increase of more than two degrees (IPCC 2014). This situation emphasizes the need to restrict emissions in the short-term.

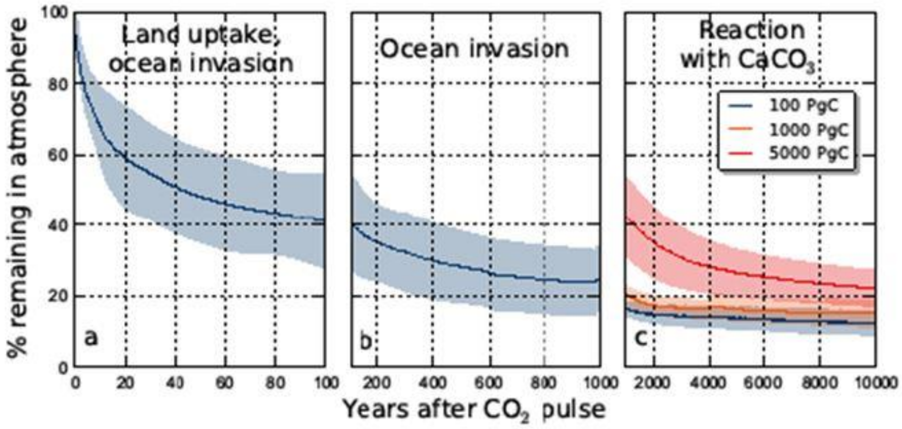


Fig 4. a) and **b)** The percental decrease of carbon dioxide concentration in the atmosphere over time caused by a carbon dioxide emission pulse (100 PgC) at time 0. **c)** The percental decrease of carbon dioxide at emission pulses of 100, 1000, and 5000 PgCs (IPCC 2013). The figures show the effects of carbon dioxide emissions of all types (both fossil and bio-based) on the development of atmospheric carbon dioxide concentrations.

The Dutch (van Vuren et al. 2009, 2011) have outlined a global emissions reduction pathway (the so-called RCP 2.6), which would most probably prevent a two-degree temperature increase on earth. According to this outline, global greenhouse gas emissions by 2050 must be half of the level recorded in 2000, and by 2100 they must be at 10% of the 1990s levels (Fig. 5).

Land use emissions are also incorporated into this scenario. The projection assumes that bioenergy utilization will increase significantly from current levels. However, the emissions reduction pathway has confined the additional production of bioenergy to abandoned farmland. Furthermore, deforestation will concurrently significantly decrease. The emissions from bioenergy and other forest utilization forms are not taken into consideration in countries such as Finland, where forest carbon sinks are assumed to remain at the 1990s level.

Certain countries must progress at a more rapid rate in their GHG emission reduction than others, if the pathway RCP 2.6 is to be implemented (IPCC 2014). The effort sharing between countries has currently not been performed. A starting point for the sharing in climate negotiations has been the division between developed and developing nations. Wealthy nations, Finland included, have pledged in the UN climate agreement to decrease their emissions at a more rapid rate than developing countries (United Nations 1992). The OECD among others has outlined the effort sharing (OECD 2012).

Finland has committed itself to the European Union goal of decreasing greenhouse gas emissions by 80–95% from 1990 levels by 2050 (Työ- ja elinkeinoministeriö 2013, 2014). In practise, this would require Finnish energy production to be carbon neutral, as bringing agricultural emissions down is difficult (IPCC 2014). For RCP 2.6 emissions development to be actualized, wealthy nations, such as Finland, would have to achieve an emission-free, even carbon negative, situation. In practice this means removing greenhouse gases from the atmosphere using one mechanism or another. This can be accomplished e.g. by increasing forest carbon sinks, applying carbon dioxide separation and geological storage into biomass fuels (BioCCS), or by removing atmospheric carbon dioxide using artificial photosynthesis (IPCC 2014).

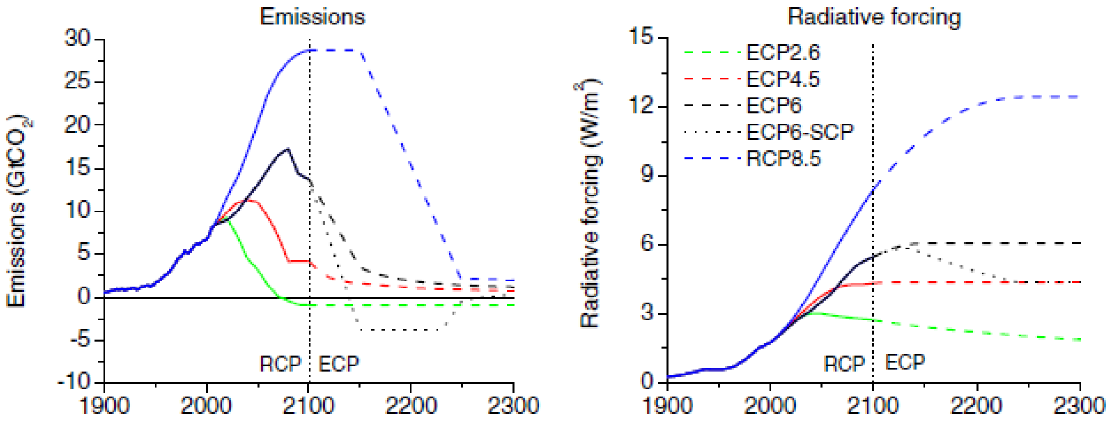


Fig. 5. Various global emissions development pathways prior to 2100 (RCPs) and after it (ECPs), and their corresponding radiative forcings (van Vuuren et al. 2011). The green line shows the emissions reduction pathway (RCP 2.6) that would most likely avoid a two-degree temperature increase on earth. The radiative forcings of emissions will continue at a high level for centuries onwards, even if the emissions are greatly decreased in the emissions reduction pathways before 2100.

The IPCC (2014) report has considered the possibility that greenhouse gas emissions will surpass the target track of the RCP 2.6 pathway. If this will occur, it is still possible to keep the earth's temperature increase within the two-degree limit as long as emissions are reduced at a greater rate. The IPCC report speaks of a so-called overshoot situation in atmospheric carbon dioxide concentrations, where concentrations momentarily surpass a critical level. “Allowing” such surpasses is partly based on the notion that short-term emissions development is not critical for climate warming. Instead, cumulative emissions development is essential. Additionally, it is assumed that irreversible feedback mechanisms initiated by nature itself do not occur (compare with permafrost thawing in Schuur et al. 2015). Meinshausen et al. (2009) and the IPCC report (IPCC 2013) among others have emphasized the strong dependence between cumulative CO2 emissions and temperature increase (Fig. 6).

The rapid decreasing of fossil fuels is clearly emphasized in the climate change control strategy of the IPCC assessment report (IPCC 2014). The idea that the forest-based carbon dioxide released into the atmosphere will fairly rapidly return to the forest carbon cycle is the baseline for handling the carbon dioxide emissions released through forest biomass utilization. The carbon dioxide released through forest utilization has not been considered to influence climate change development, as long as forestland remains forestland and its production ability is not integrally weakened after wood biomass utilization. However, a considerable amount of the biomass in global-level assessments is either short-rotation wood or the byproducts or leftovers of agriculture (IPCC 2011). The situation is different for fossil fuels (see section 4.1). The carbon dioxide released during wood utilization is removed from the atmosphere during the tree's rotation period, and is transformed back into tree carbon. Despite the time lag (carbon debt), this is seen as a part of the decrease strategy of fossil fuel utilization. The strategy for forest climate change control is focused on stopping deforestation.

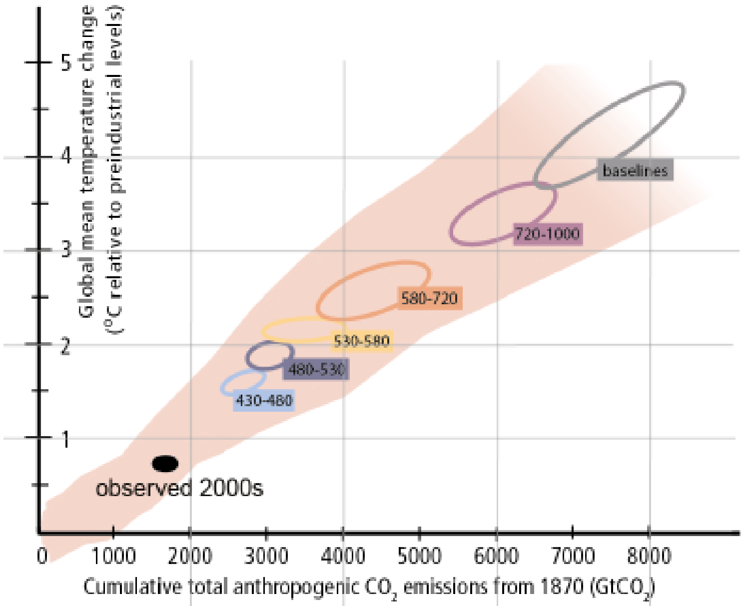


Fig. 6. The connection between average global temperature change and the cumulative human-induced carbon dioxide emissions since 1870 (IPCC 2013). The average temperature change is nearly proportional to the carbon dioxide levels released into the atmosphere.

3.2 Measures related to forests

The effects of the actions directed at Finnish forests, e.g. forest carbon storage levels, can target a forest stand, the forest holding of one forest owner, a wide forest area, or all Finnish forests as a whole (Fig. 7).

A forest holding is the basic unit of practical forestry. Silvicultural practices and harvests are usually planned at the forest holding –level, using either even-aged structure along with thinning and regeneration cuttings, or uneven-aged structure along with selection cutting. Finnish forests are usually described using a combination of tree species and forestry practice, e.g. a planted birch stand.
A forest holding is a forest area owned by one forest owner. It is made up of one or several stands. Forest planning in Finland is usually carried out at the forest holding level. Forest management practices

(harvests, silvicultural measures, conservation, etc.) and directing them at different stands during the planning period are planned out according to forest owner objectives.

When examining carbon stock changes we gain a very different picture depending on whether the examinations are made for one stand or an entire forest holding (or wide forest area) (Fig. 8). In a stand-level examination forest carbon stocks fluctuate greatly due to regular harvests that target most of the stand. In forest holding and area –level examinations, forest carbon stocks grow accordingly as new stands are established, until the area is “saturated” with stands of varying age. The effects of yearly harvests on forest carbon stocks are not visible at this level because harvests target only 1/90 of the entire forest holding at one time.

When examining the climate effects of forest carbon stocks and sinks from the viewpoint of climate politics and society, it is important to observe the following scales of the practices (Fig. 9): forest management (forest owner actions), development of Finnish forests (wood utilization, climate change effects, etc.), the societal importance of trees in Finland, and the effects of the international climate agreement and guidance mechanisms of the EU.

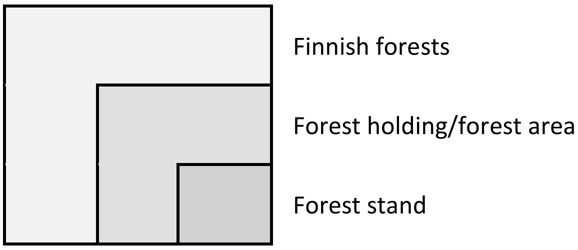


Fig. 7. Scale of the practices affecting Finnish forests

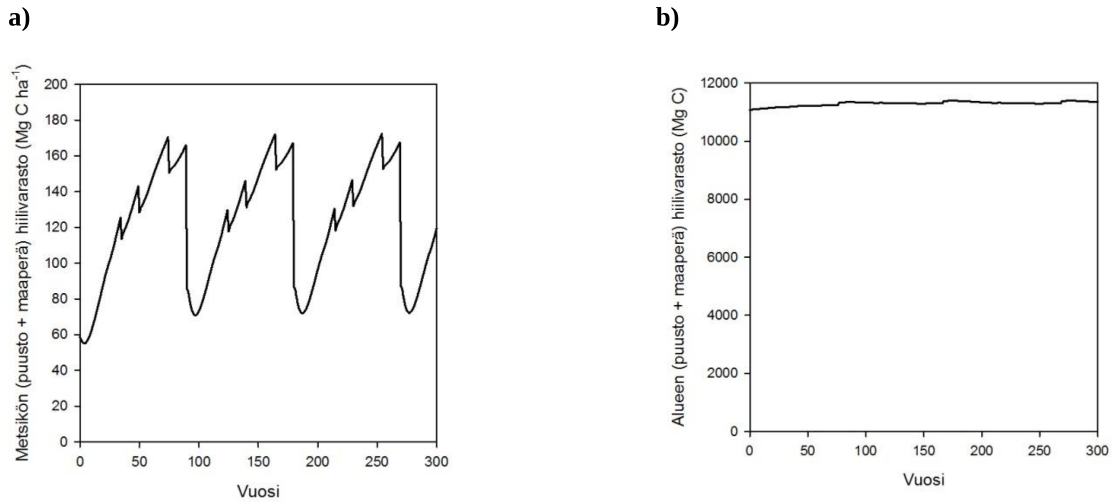


Fig. 8. a) Carbon stock development (Mg C ha-1) of forest trees and soil in a Finnish pine stand, with a rotation period of 90 years. Three thinnings are conducted at 35, 50, and 75 years of age. **b)** Growing stock and soil carbon stock (Mg C ha-1) development in a forest area (forest holding) that is comprised of 90 pine stands described in (a). Equal-sized stands are established each year and felled according to (a). The simulation has been carried out using the CO2FIX model (Masera et al. 2003). Raw data are from Koivisto (1959) and Marklund (1988). A legend in the y-axis of Fig. 8a): Carbon stock of a forest stand (growing stock and soil) Mg C ha-1. A legend in the y-axis of Fig. 8b): Carbon stock of a forest area (growing stock and soil) Mg C ha-1.

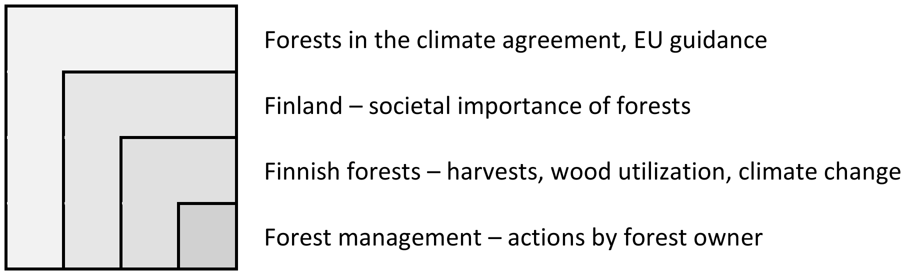


Fig. 9. Forest and climate politics scales in relation to the climate impacts of forest carbon stocks and sinks

It is important to observe the following aspects in the forest management –scale:

- Effect of forest management on carbon balance of stand
  - Harvesting practices (regeneration cuttings, uneven-aged management, etc.)
  - Behavior of forest owner
  - Tree species choices
  - Timber harvesting
  - Effects of forest energy harvest
- Other forest management factors affecting the climate (albedo, aerosols)
- Other environmental changes caused by forest management (biodiversity, erosion, soil nutrients etc.)
- Disturbances

It must be noted that political guidance targets the decision-making level of silviculture, despite political decisions being made at the national and international levels, and carbon balance development assessments being made at the national level.

It is important to observe the following aspects when examining the Finnish forests –scale:

- Wood utilization scenarios (wood and product prices, etc.)
- Wood utilization level effects on Finnish forest carbon balance
- Wood utilization level effects on forest albedo and the formation of aerosols
- Climate change effects on Finnish forest ecology (growth, total removal, disturbances, etc.)

It is important to observe the following aspects when examining the societal importance of forests –scale:

- Climate policy
- Forests as a strategic natural resource – the aims and challenges of bioeconomy
- Bioenergy utilization and its effects
- The potential for utilizing forests (conservation needs, etc.)
- Timber sales and conservation willingness of forest owners
- Employment policy
- Energy policy

It is important to observe the following aspects when examining the international affairs –scale:

- Forests as part of an international climate agreement – provides a working frame for Finland's actions
- Forests as part of Finland's emissions reductions objectives
- EU regulation (bioenergy etc.)

Forest and climate policies can be divided into the following time spans: short, mid-, and long-term.

Short term (10–30 years)

- Time span for political actions, e.g.
  - International emissions aims until 2050
  - EU climate aims for 2030
- The climate change impacts of forest harvesting and silvicultural activities are visible (greenhouse gases, albedo, aerosols)
- We have fairly reliable estimates of Finnish forest carbon source and sink development for this time span

Medium-term (50–100 years)

- Ecological time span of trees and forests
- Wood utilization changes are visible at this time span
- Effects of climate change begin to show in relation to forest growth
- Forest change effects on the climate (greenhouse gases, albedo, aerosols)

Long-term (100+ years)

- Time span for long-term effects of climate change – clear changes
- Great uncertainty in several models and scenarios visible at this time span

4. CLIMATE IMPACTS OF GREENHOUSE GAS EMISSIONS CAUSED BY FOREST UTILIZATION

4.1 Forest carbon balance changes and climate impacts

Baseline

The climate change debate related to forest utilization often includes an assumption of the carbon neutrality of forest biomass. This is apt for creating a positive image of the climate impacts of wood utilization. The problem is that carbon neutrality as a term has been used in slightly different ways in various contexts. In common language it even means that an action does not cause any climate impacts at all. The climate panel (Seppälä et al. 2014) defines carbon neutrality using a definition that is in line with the international convention: “carbon neutrality is a condition, where anthropogenic greenhouse gas net emissions as carbon dioxide equivalents are zero at a pre-defined time period”.

This abovementioned definition is appropriate when companies, regions, and cities strive for carbon neutrality. In this case the time frame used is usually a year, during which emissions balance should be zero. From a forest viewpoint the carbon neutrality term is practically limited to the carbon cycle (e.g. Matthews et al. 2015). Other special characteristics have additionally been connected with it, and have caused the term to be used in slightly varying ways when examining forest utilization. These depend on the extent of the examination target, the greenhouse gases included in the calculations, the substitution benefits of the wood products, the comparison situations, and the time frame.

Carbon released into the atmosphere from forest biomass is generally considered to be carbon neutral, because the carbon in forest biomass is part of the fairly rapid natural carbon cycle. It is believed to influence atmospheric CO2 concentrations only if the carbon cycle is no longer in balance with the forestland (e.g. Lucier and Miner 2010). In practice this balance is shaken if forestland is destroyed and trees once removed from the area can no longer grow back. Approximately a quarter of the carbon with fossil origins released into the atmosphere is currently globally fixed in forests, i.e. the short-term carbon cycle (Fig. 10). Despite this, fossil-based carbon dioxide emissions enter the biosphere (vegetation and oceans) from the outside and increase atmospheric carbon dioxide concentrations for thousands of years, because of the limited carbon-fixing ability of the biosphere.

The abovementioned commonly used definition for climate neutrality is only linked to forest carbon balance and its changes. This interpretation creates the basis for forest raw materials being carbon neutral in the long-term as long as a logging area remains forestland, and its original carbon storage with trees and soil returns to its initial state. In this case the climate neutrality interpretation does not consider the changes in greenhouse gases released during forest management throughout its life cycle or other climate impacts of forests (albedo and aerosols) (see section 6). The climate neutrality of forest raw materials therefore does not mean that their utilization has no negative or positive climate impacts.

The carbon balance of forest utilization appears different in the national-level viewpoints of individual countries versus global comparisons. Yearly country-level estimates can be made for forest greenhouse gas balance based on results from the forest section of the greenhouse inventory (compare with section 2.2). The forest utilization of a specific country is therefore not climate neutral if a forest carbon sink does not exist, i.e. the forests release more carbon than what they fix.

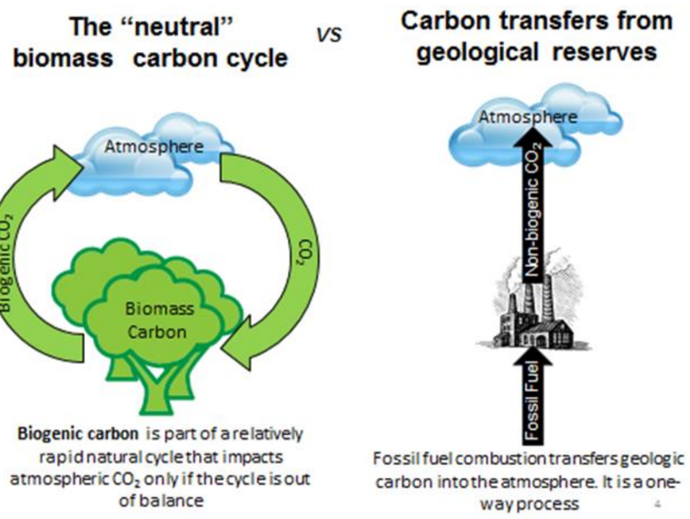


Fig. 10. Differences between the carbon dioxide release of biogenetic and fossil carbon stocks (Lucier and Miner 2010).

The abovementioned interpretation of carbon neutrality, according to which utilizable forest biomass is carbon neutral if the carbon sink remains of equal size or grows larger, has gained support from the world's sustainable development enterprise organization (WBSCD 2015). The foundation for this interpretation is that forest carbon balance development is followed at the scale of a certain wide area, e.g. at the nation level, while concurrently accepting a time-bound reference point used to follow the occurring change. Therefore e.g. the utilizable forest biomass of Finland is climate neutral, as our forest carbon sink is greater than during 1990, and it is even assumed to grow to some extent in the near future despite the apparent growth of forest utilization. As Finnish forests fix more carbon dioxide than they release, their net effect on the climate is cooling, i.e. their climate impact is clearly positive.

The current UN climate agreement has in part strengthened the connection between the climate neutrality concept and the preservation of carbon sinks. The reduction objectives for energy-based greenhouse gas emissions are tied to the emissions level of 1990. The monitoring year for the emissions inventory of the land use sector (LULUCF) also begins in 1990, and in practice, the conservation obligation for forest sinks in the current climate agreement in developed countries is also bound to this same year.

The previously presented interpretation of climate neutrality has been widely used, which has also created a general belief in the importance of forest utilization in curbing climate change. However, recent studies have questioned the traditional use of this term, because it does not consider the carbon sequestration potential of forests and the time frame questions related to it, which are meaningful when estimating the role of forests in climate change mitigation. This will be clarified in the upcoming sections.

Estimating forest carbon balance development and its climate impacts

The impacts of a single forest's management practices on the whole area's carbon balance and carbon neutrality can be seen as an entity, differing from how things appear at the national-scale. The carbon cycle of a single tree or separate trees can be used as the baseline for estimating the carbon balance changes of forest based biomass. In the simplest process, a tree or stand is felled at the end of its rotation period. In reality, in Finland a stand's rotation period often also includes thinnings. Changes additionally occur in the growth conditions of forestland over time. These aspects complicate the processing of the biogenetic carbon cycle, but in the following we will break down the analysis of climate neutrality through a simplistic "trees are felled – trees grow – trees are felled" –thought process.

Harvests cause a carbon debt in the stand. Carbon neutrality is realized at a certain time delay when total removal is replaced through new growth. The rotation time of the regrowth of a tree depends greatly on the tree species, geographic location, and growth conditions. For example, the rotation time of a eucalyptus plantation is 10–11 years, while the rotation time may be over a century for a pine growing in southern Lapland. Simplistically considering, eucalyptus-based bioenergy is carbon neutral in 10–11 years, while the bioenergy based on a pine growing in southern Lapland reaches carbon neutrality in a century. In reality the same amount of carbon can accumulate compared to the initial circumstances before or after the rotation period, because the forestland net carbon balance can either decrease or increase during the rotation period of the trees. The carbon balance of a stand is formed through the changes in the carbon stock of growing biomass and soil (including the effects of forest litter production).

The abovementioned mindset is simply based on forest climate neutrality being attainable, when the carbon debt created through harvests is replaced by additional growth. In this case the forest carbon balance prior to harvests is accepted as the comparison or reference situation, to which the change is compared. Such a reference point, based on the reversibility of the initial starting condition, is only one way of defining the reference situation.

The impacts of forest harvesting and utilization procedures on forest carbon balance development can generally be assessed using the following equation

$$\Delta C = C_u - C_r \qquad (1)$$

where ΔC is the change in forest net carbon balance in relation to the chosen reference condition at time span t_1-t_0, C_u is the cumulative carbon accrual according to the harvests and utilization scenario of the tree, and C_r is the carbon accrual based on the reference scenario. Therefore, the baseline is that the carbon released into the atmosphere through the forest biomass removed from the area (total removal) is subtracted from the C_u balance. The chosen utilization scenario for the tree (e.g. half of the tree becomes a wood construction product) influences the end result when the carbon storage of wood products is considered (e.g. Kilpeläinen et al. 2013). The carbon stored in wood products therefore positively influences the carbon deficit repair in the forest. On the other hand, the carbon of biomass to be burned is immediately lost from the C_u.

Forest carbon debt implies that the carbon removed from forests is either within the products or as carbon dioxide in the air. The greater the emission and the longer the forest carbon debtt is visible as a carbon dioxide emission in the atmosphere, the greater the created radiative forcing, i.e. negative climate effect. The size of the climate effect is affected by the reference point to which the forest carbon balance development is compared.

The baseline of the carbon neutrality concept, defined by the Finnish Climate Change Panel (Seppälä et al. 2014), is to assess the impacts of human actions on the formation of the carbon balance. This assessment is possible if C_r in equation (1) is the development path of forest carbon balance from a starting point t_0 to time t_1, excluding human actions. This is compared to the tree harvets and utilization scenario C_u. If ΔC is larger than 0 at a certain time span t_1-t_0, then carbon neutrality is realized during this time. A great source of uncertainty originates from the calculation of forest carbon balance without harvesting, because describing natural forest development dynamics is challenging using process models, and simpler models are principally based on measurements from managed forests.

Whether the conditions prior to harvests, or forest carbon balance development without harvesting, are chosen as the reference point significantly affects the end results of the calculations (Fig. 11). The reference point where forest utilization does not occur better fits the requirement, when assessing future human actions on the climate (e.g. Helin et al. 2013, Soimakallio et al. 2015). This is also the recommendation of the IPCC (Smith et al. 2014). The first-mentioned reference point is more of a political decision when wishing to retain forest carbon stocks at a certain level. This has also been used as the basis for the international climate agreement for developed nations.

Until now equation (1) has been approached through stand-level comparisons that help understand the climate effects of single actions at the stand level. However, the situation changes if a wide geographical area, with stands at varying phases of the rotation cycle, is set as the basis of the comparison (see Fig. 8). The carbon debt of the entire area may, in this case, go unnoticed if the area's carbon balance prior to harvests is used as the reference point (see Fig. 8b).

In practice, equation (1) is used to also assess the carbon balance development of wide geographical areas and at the country level. In this case, a sensible baseline is to assess the change in utilization level of forest raw materials and its effects on the area's carbon stocks (e.g. Ros et al. 2013, Matthews et al. 2015). This follows various forests at different stages of the harvest cycles and their carbon balance change between various harvest scenarios. Rather than following the carbon debt of a single harvest event, the changes caused by continuous harvesting is looked at. This change results in the new wished forest utilization level. This is a so-called contrasting reference point (see the next section and Ohrel 2012), which is a relevant analysis method in political decision-making.

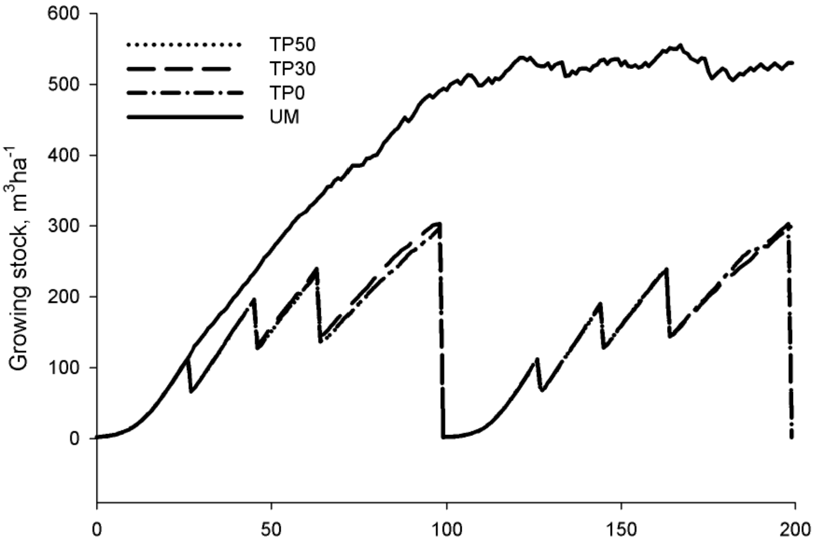


Fig. 11. A schematic picture of how the various reference points affect forest carbon balance development assessment. The picture outlines the carbon storage development of forest growing stock over the past 200 years, with two final harvests at ages 100 and 200 years and thinnings carried out in-between (the lower curves in the diagram: TP50, TP30, and TP0 depict various harvest and management scenarios with slight differences). The higher line (UM) describes a SIMA model simulation of how the carbon storage of forest growing stock was to develop without any harvests. The area between the highest line and lowest lines shows the carbon stock loss in growing stock. When assessing equation 1, if the reference point used is time 0 and the growing stock's carbon storage is the normal size before a final harvest (approximately 300 m3ha-1), then the carbon neutrality of the forest raw materials will be actualized within 100 years, even though all the felled wood would be burned and forest soil carbon balance changes are not considered. If forest development without harvest (upper picture) is set as the reference point, the forest biomass carbon debt will be the difference between forest soil carbon storage decrease and the utilization of forest wood mass. Including forest soil carbon balance changes alters the before-mentioned comparison (see Kellomäki et al. 2013). The picture is from Kilpeläinen et al. (2013).

If examining the climate impacts caused by changes in wood utilization levels is the objective, then C_r in equation 1 could e.g. be a harvest scenario complying with current forest management recommendations along with the scenario's usage demands. C_u could be a new scenario. Assessments such as this have been conducted both domestically and internationally (see chapter 4.2). For example, when examining the change in utilization level in Fig. 1, additional forest utilization appears to lead, at least in the short-term, to the permanent decrease of carbon sink size in Finland. In this case, the critical question is what climate benefits can be gained with the forest biomass removal between these scenarios in relation to the lost or augmented forest carbon sink compared to the time frame in question. In this case the significance of the usage demands is emphasized. The better the wood products or wood energy can be used to replace actions causing emissions, the faster the biomass "carbon deficit" created in a forest by the management actions can be repaired.

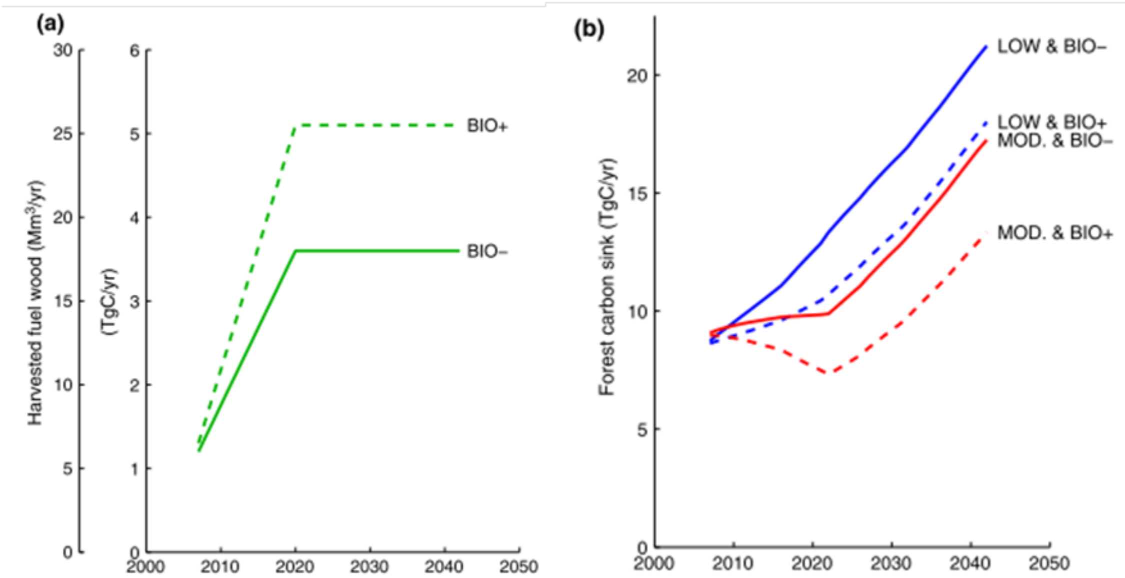


Fig. 12. a) Forest energy scenarios BIO- and BIO+, and **b)** carbon sink development in Finnish forests according to four different utilization scenarios (Pingoud et al. 2015). BIO+ corresponds with the bioenergy policy of the Finnish energy and climate strategy (Työ- ja elinkeinoministeriö 2013). The scenarios and results are from Asikainen et al. (2012) and Sievänen et al. (2014).

BIO- = the amount of energy wood changes from 7 million Mm3/year (2007) -> 18 million Mm3/year (2020)
BIO+ = amount of energy wood changes from 7 million MM3/year (2007) -> 25.5 million Mm3/year (2020)
LOW = raw wood utilization decreases from the current ca. 50 million Mm3/year (2007) -> 43.9 million Mm3/year (2020)
MOD = raw wood utilization increases slightly, 50 Mm3/year (2007) -> 56.6 million Mm3/year (2020).

4.2 Climate impacts of wood products and forest energy

The recovery time of the forest carbon debt caused by harvests creates the basis for examining the climate impacts of human activities and biomass utilization. This time depends on forest growth and the storage time of carbon within products. When assessing the climate impacts of wood products and forest energy, it is also important to consider the compensation benefits received, when the products and energies are used to substitute alternative products and energy forms with large greenhouse gas emissions.

Wood product and forest energy utilization require various stages for their realization. These include forestry management practices, wood harvesting, product manufacture, distribution, and utilization. Each stage uses fossil fuels. Therefore, when conducting carbon neutrality assessments on wood products and forest energy, life cycle greenhouse gas emissions should be added to the harvest and utilization scenarios as C_u-emissions in equation 1. This should be done when differentiating between the relative order of the various scenarios in terms of their climate impacts. Correspondingly, the life cycle greenhouse gas emissions of products replaceable by wood should be assessed. In a comparison situation the emissions of these competing products are added to the emissions of the reference condition. The sensibility of using wood products and forest energy to decrease greenhouse gas emissions can then be assessed using equation 1. In this case C in the equation is replaced by the climate effect of the greenhouse gases (GHG). If ΔGHG is greater than 0 at time t_1, the utilization of wood products or forest energy is better from a climate perspective compared to other rivaling products.

When examining the climate impacts of wood products and forest energy, the same logic applies as during the reference point presented in the previous section concerning the climate impacts of carbon balance.

The temporal development of the carbon dioxide emissions from forests and forest products is connected to an examination of product and energy systems greenhouse gas emissions, which is based on a life cycle assessment (LCA). When examining climate effects, created from a decision that changes the level of wood utilization, it is necessary to carry out a consequential LCA (see Matthews et al. 2015). As a whole, the climate effects of this decision are formed of all the factors that change due to the decision (e.g. reactions of the forest carbon stock and energy system to the changed conditions). A consequential analysis is complicated, and contains considerable uncertainty (Zamagni et al. 2012).

In addition to carbon dioxide emissions, life cycle-based product and energy comparisons also often consider laughing gas (nitrogen oxide) and methane emissions released at various life cycle phases, and possibly F-gases. The total climate impact of greenhouse gases is typically calculated as carbon dioxide equivalent values, which are gained by multiplying greenhouse gas emissions with their so-called GWP potential coefficients. In this case, the heating effect of various gases is commensurated to correspond to the heating effect of carbon dioxide emissions during a 100-year time period. However, this is a simplification of the so-called radiative forcing quantity models, which offer calculation options that can present the climate impacts of the total emissions of various products and energies at various moments in times (e.g. Monni et al. 2013, Holmgren et al. 2006).

The size of positive climate impacts, i.e. climate benefits, attainable through wood products and forest energy utilization, changes with time as a forest refixs carbon dioxide back from the atmosphere into new growth. Climate benefits of wood products and wood energy can only be attained once the cumulative radiative forcing released at various times into the atmosphere from the entire process chain is smaller than the cumulative radiative forcing of alternative products and energies.

Forest energy

Irrespective of the reference points for forest carbon balance, the performed energy examinations show that the carbon debt formed in forests through harvesting is slowly replaceable, even though the substitution benefit of forest energy in relation to fossil fuels is considered. How rapidly the harvest-induced carbon debt can be compensated with new growth is one factor influencing how rapidly the climate benefits of forest energy become visible.

The reversibility of forest energy carbon balance is weakened already at the starting point by more carbon dioxide being released from wood energy per produced energy compared to fossil fuels.

The emissions coefficients for bioenergy, coal, diesel oil and natural gas in energy production are 109.6, 93.3, 73, and 56.1 g CO2/MJ, respectively (Tilastokeskus 2015b). Power plants can additionally reach a slightly higher efficiency for fossil fuels in energy production than for wood (Ros et al. 2013). However, no practical difference can be seen between coal, gas and wood in the life cycles other than burning greenhouse gas emissions per produced energy (Tilastokeskus 2015b). The starting point is weakened also by the fact that felled forestland acts as a carbon source for years before the new biomass growth fixs more carbon than what is released through soil and vegetal detritus decomposition (Tuomi et al. 2011, Liski et al. 2006, Kilpeläinen et al. 2013).

The GHG emissions of fuel production do not play a significant role in the climate effect comparison of forest energies. The significance of other life cycles, apart from combustion, in Finnish forest bioenergy greenhouse gas total emissions is only 2–3% according to e.g. the literature review conducted by Repo et al. (2012).

Because of the abovementioned reasons the model examinations in the boreal forest zone produce a result, in which the greenhouse gas emissions balance per produced corresponding energy amounts for forest energy, measured in CO2 equivalents, is worse than the fossil-based emissions balance of oils and natural gas for a long time in the future. The greatest net emissions are formed when growing trees are directed towards energy. The harvestable biomass, geographical location of the harvest site, and time period incorporated in the calculations effect the reversibility of the carbon debt created by the forest harvest and utilization scenario.

The size of the attainable climate benefits changes with time as the forest fixs atmospheric carbon back into new growth. The literature refers to the time needed to gain the benefits from climate impact via energy as the payback time. In addition, a so-called atmospheric carbon parity point determination is used to assess the climate benefits of forest energy. It denotes the time when the reduction in carbon emissions from the substitution of fossil fuels is equal to the loss in forest carbon stock through bioenergy utilization (Fig. 13).

In practice, both radiative forcing calculations and cumulative carbon dioxide emissions calculations have been used to determine the payback time. Only small effects can be seen in the results (Holtsmark 2012a). On the other hand, choosing the reference point and the calculation method – the reversibility of a single forest carbon debt or the simulation of continuous harvesting in carbon balance follow-up – influence the end result (Holtsmark 2012a). When calculation choices are combined with very different material bases and replaceable fossil fuels, the literature finds very varying payback times for forest energy (e.g. Agositini et al. 2013, Matthews et al. 2014). They are less than ten years at best, or several centuries at worst.

Various model examinations uniformly show that the use of slow growing wood for energy utilization does not attain short-term climate benefits despite wood energy replacing fossil fuels (e.g. Holtsmark 2012b, Ros et al. 2013, Agostini et al. 2013). Replacing the wood from additional harvests with coal and peat attains the best substitution benefits in energy production. However, even in this case the climate benefits would be realized for slowly growing Finnish wood (with e.g. a rotation period of 75–90 years) only in the medium-term if the forest carbon balance prior to the harvest is used as a reference point. If the BAU development of forests with no additional harvest operations is set as the reference point, climate benefits compared to fossil fuels are attained only in the very long-term (190–340 years with increased harvesting in the boreal forest zone when forest growth is assumed to remain at the current rate in the future, Holtsmark 2012b). Replacing coal provides the shortest payback time (190 years), while traffic fuels produce the longest payback time (340 years). Ross et al. (2013) have calculated longer payback times than Holtsmark when wood is used to replace coal. Time span for the atmospheric carbon parity point of forest energy produced from industrial wood in the boreal forest zone is considerably longer than the payback times, and defining it is not meaningful due to the future climatic uncertainty factors.

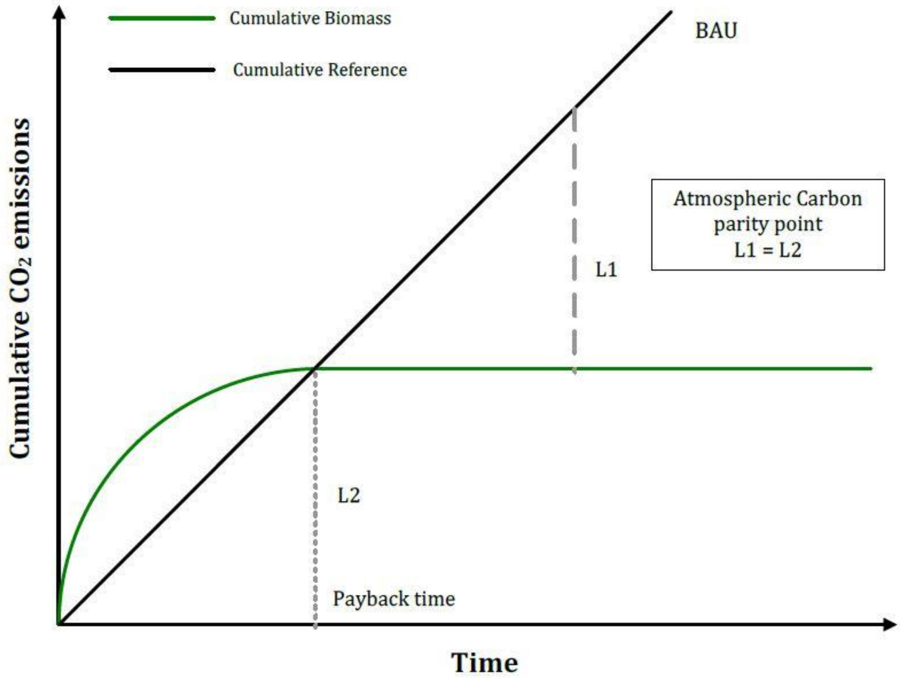


Fig. 13. Visual representation of the payback time and parity point of atmospheric carbon. Green line: carbon stock decrease in a forest caused by bioenergy production. Black line: cumulative carbon dioxide emissions reduction due to forest energy replacing fossil energy (Agostini et al. 2013).

The significance of increased harvesting on Finnish forest carbon stocks and sinks, and the climate impacts of products and forest energy are approached in practice by the model assessing the carbon stock change of current usage and additional utilization in relation to time. Accounts by Kallio et al. (2013), Sievänen et al. (2013), and Pingoud et al. (2015) among others show that climate benefits will not be attained by 2050 by employing increased utilization scenarios for wood in the upcoming years, where total removal from the forest is increased and even used to replace fossil fuels. For example, Pingoud et al. (2015) have shown that increasing energy wood harvest from 18 million m3/year to 25.5 million m3/year cannot bring in climate benefits in the 35-year comparison period, even if additional wood were used to replace fossil fuels (compare Fig. 12). The forest energy emission coefficient calculated in this way varies from ca. 120–220 g CO2/MJ, increasing nearly linearly with time. This holds true even if carbon sinks increase because the carbon sink lost in forests is greater than the carbon amount of forest-harvested wood, and, on the other hand, wood emissions per produced energy amount are higher than with fossil fuels. In light of these examinations the additional utilization of forest energy does not produce climate benefits, at least in the short-term. The time span required to achieve a climate benefit cannot be stated based on these investigations, as they will conclude by 2050.

The climate benefits of wood utilization can, however, be attained in the short-term (10–30 years) by directing into energy production the fairly rapidly decomposing forest slash, such as branches and thinning wood, otherwise left to decompose into the soil. Repo (2012) notes in her study, based on the continuous use of logging slash, that with passing time the emissions coefficients of the energy utilization of logging slash changed from 105 to 21 g CO2-eg MJ-1. Emissions are greatest when the energy utilization of logging slash is begun or increased. However, emissions decrease with time because the slash will decompose, releasing carbon dioxide even when left in the forest. In the study, the carbon dioxide amount decomposing from the slash, which would otherwise have been released from the slash in the forest, was subtracted from the emissions from slash burning with time. When branch energy utilization had continued for 20 years, the emissions were 47 g CO2-eq MJ-1 and 21 g CO2-eq MJ-1 after a century. The size of the net emissions therefore depends on the decomposition rates of slash. The energy utilization of rapidly decomposing branches therefore causes emissions half the amount of those from slowly decomposing stumps (Repo et al. 2012). In a study by Jäppinen et al. (2014), the emissions from slash, stumps, and small diameter energy wood differ between 10 and 40 g CO2-eq MJ-1 with an emissions time frame of 100 years.

The emissions from slash energy utilization can, however, be improved using silvicultural mechanisms (see Kalliokoski and Repo 2015). The problem is that the amount of these fractions is finite, as their formation is dependent on the creation of industrial wood and stemwood.

Ros et al. (2013) showed in their report that wood residues and slash utilization for producing biodiesel using the Fisher-Tropsch technique produces climate benefits already in the short-term, and the payback time for the carbon emissions varies from a few years until 45 years depending on the raw material base. The payback time of gassing varied from 11 to 27 years. However, justifying increased harvesting for the manufacture of traffic fuels is not justifiable for climate reasons even in the medium-term, and attaining climate benefits occurs in a longer time frame than replacing coal in energy production. The energy inefficiency of biofuel production compared to fossil traffic fuel production and the fact that traffic fuels have smaller specific emission coefficients than coal. The energy utilization of forest biomass therefore has worse climate effects when used as traffic fuels than in power plant production, especially in CHP production.

Decreasing wood rotation times has often been suggested as a way of improving the climate sustainability of bioenergy (Agostini et al. 2013, Matthews et al. 2014, Matthews et al. 2015). In practice this would require favoring tree species that grow faster than the original trees and/or well-timed silvicultural practices. The climate benefit of each management practice greatly depends on the baseline of the "forest field", the natural resilience of the area, and the competing usage forms of the substrate. If wasteland and naturally slowly regenerating fields, left out of agricultural usage, are reforested, the climate benefits of the management action are apparent even in the short-term, unless the field land competes with other utilization needs. Otherwise climate benefits may be lost because forests elsewhere are being converted to cultivation fields. If the baseline is converting current forestland to fields, the original forestland carbon stock diminishes for a long time in the future or even permanently (Matthews et al. 2015).

Directing various wood residues into energy utilization has also been mentioned on several occasions as a way of gaining short-term climate benefits for forest energy (e.g. Miner et al. 2013, Matthews et al. 2015). This is valid if the alternative is to leave biowaste unutilized. The situation would be different if e.g. sawdust could be used to make wood products with service time of several decades (see the next section "Wood products").

Matthews et al. 2015 have produced bioenergy production scenarios for all of Europe. Based on these scenarios, bioenergy utilization will significantly decrease the EU's emissions by 2050. In addition to wood energy, the various forms of field energy are also a source of bioenergy. However, the calculations cannot differentiate the significance of Finnish forests in the emissions development.

Wood products

Wood can be used to make various products, the carbon content of which is released into the atmosphere according to various utilization and recycling alternatives. The carbon in most paper products is released within 1–10 years, while the release time for carbon in construction materials may vary from 20 years to over a century (Ros et al. 2013). The longer carbon is bound in a product, the better the climate impact gained in the short-term, as the carbon debt of a forest can decrease already during the beginning of the examination period. For example, Cherubini et al. (2012) have estimated that even a 10-year storage period for carbon in a product decreases the corresponding carbon dioxide emissions' climate impacts at a

100-year time frame. New growth will have repaired the carbon debt created in the forests within 10 years. If storage can be upheld for 40 years, the climate impacts decrease by 30% in a 100-year time frame.

The longevity of wood products can be increased through product planning, reuse, and cascade use. Cascade use indicates actions, in which the wood content of a product is reused over and over again in new products. Carbon storage in wood products is visible in the greenhouse gas emissions inventories. In 2012 the carbon bound in wood products produced in the EU accounted for ca. 10% of the carbon sink of the EU (Nabuurs et al. 2015). This percentage was at the same level in Finland, which corresponds to ca. 5% of the fossil and process-derived greenhouse gas emissions (Tilastokeskus 2014a).

Wood-produced products can be used to replace products with worse life-cycle emissions. It is possible to make emissions estimates for the substitution impacts of wood products using life cycle assessment (LCA) in which the results of models estimating economic substitution effects can be utilized. Wood energy emissions must also be considered in these assessments. Currently ca. half of the wood biomass from mechanical forest industry and chemical pulp production is directed into bioenergy utilization. In 2010 the raw wood usage of the mechanical forest industry and chemical pulp industry was 7.45 and 29.37 million m3, respectively (Metsäntutkimuslaitos 2011). In LCA assessments these energy production emissions should be included as emissions from products made from chemical pulp (e.g. paper and cardboard), which affects the temporal development of their climate impacts and the size of the substitution benefits from these products compared to rival products. The same applies to mechanical forest industry products. Old stemwood is the main source of this bioenergy, which is linked to the mechanical forest industry. The carbon reversibility of such old stemwood back into the forest is slow (compare with previous sections in this chapter). To our knowledge, wood product LCA assessments such as these, taking into account the temporal development of forest energy carbon dioxide emissions, have not been performed thus far.

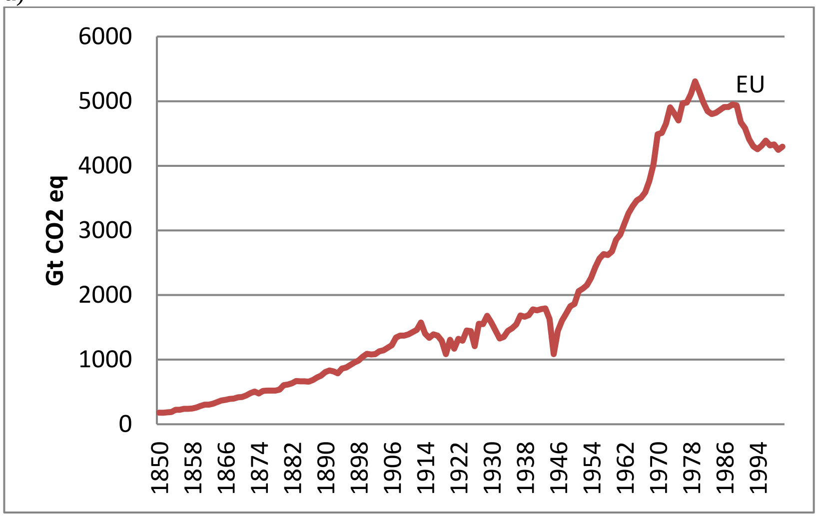
A literature review conducted by Sathre and O'Connor (2010), focused on the substitution benefits for construction products determined by various studies. According to their review, one carbon kilogram from a wood product can avoid ca. a 1–3-kg emission from an alternative product. The average of these displacement factors was 2.1. Compiling a clear summary is difficult, as the assessment criteria of various studies are not congruent.

Despite their shortcomings, the LCA assessments performed give a clear indication that replacing cement and steel in particular with wood products produces instant climate benefits. This also yields better climate benefits than replacing fossil fuels (Petersen and Solber 2005, Koskela et al. 2012, Lippke 2011). The same may apply to several chemical industry products that new bio-refineries can possibly offer. More clarification is required, as conducting comprehensive assessments is difficult. Among other things, these assessments should consider the functionality differences between applications and the service life of various materials (e.g. Koskela et al. 2012). Compensation questions should be analyzed using economic balance models in addition to LCA assessments.

4.3 Time horizon and climate implications of wood utilization

The climate benefits of wood products and forest energy utilization compared to fossil fuels are evident in the long-term. This can be seen e.g when examining estimates of the historic fossil fuel utilization emissions for the EU27 nations (Fig. 14a) and LULUCF emissions development (Fig. 14b). From 1850 until 1970 the LULUCF sector has been an emissions source in the EU27 nations, particularly because forests have given way to agricultural needs (den Elzen et al. 2013). The current land use sector emissions of the EU27 nations have turned into carbon sinks. They are forecasted to remain as such in the near future, despite forest energy utilization increasing in the EU. The role of bioenergy, most of which is made with forest energy, in energy end consumption has increased steadily in the EU28 nations from 2000 to 2010 (52.8 Mtoe → 105.1 Mtoe), and it is forecasted to reach 139 Mtoe. In 2013, just over 6% of the total energy used in the EU was produced using bioenergy, less than 4% of which was imported (AEBIOM 2015). It must be noted that the growing stock volume in the EU28 nations in 1990 was estimated at ca. 19.1 billion m3 and 24.1 m3 in 2010. Fossil fuel utilization has concurrently raised the atmospheric carbon dioxide concentration.

a)



b)

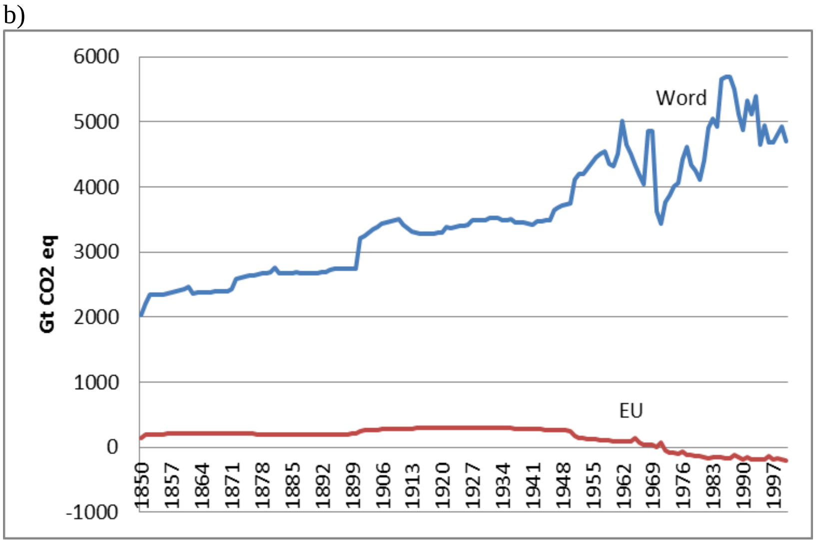


Fig. 14. a) An estimate of the emission caused by historic fossil fuel utilization in the EU27 nations in 1850–2000. **b)** An estimate of the greenhouse gas emissions by the land use, land use change and forestry (LULUCF) sector from 1850 to 2000 globally and within the EU27 nations (den Elzen et al. 2013). Picture (a) cannot differentiate between the carbon balance change of forests and forestland from the emissions development of the entire LULUCF sector. However, this can be assumed to be even more positive than that of the land use sector in light of the UNFCCC land use sector emissions data.

There are several reasons for the long-term positive development in EU-level forest utilization carbon balance. On the other hand, it demonstrates that the realization of sustainable harvest –based forest utilization is possible from the climate viewpoint when a clear economic interest is involved in forest utilization and conservation (compare with Miner et al. 2014, Fig. 15).

Chapter 4.2 highlighted the short- and medium-term emissions problem connected to wood utilization: forest energy and several wood products cause greater greenhouse gas emissions for a prolonged time compared to competing products and energies. A greater climate benefit in the short- and medium-term could be gained by leaving trees in the forest and raising the carbon stock.

On the other hand, if Finland increases its wood utilization, the country might be able to use the carbon sink option later, once forest age distribution has become younger, causing the forests to grow better. Ensuring this would require a separate study. In the very long-term, the forest carbon sink would weaken as the forests age. Without significant tree regeneration, the decomposition actions of forest biomass are of the same magnitude as its growth. The forests would thus enter an equilibrium state, i.e. they would not be either a sink or a source (but would act as a large carbon stock) (see the situation prior to 1750 in Fig. 13). In practice even forests in their natural state cannot develop into old-growths, as even they experience natural regeneration following forest fires and storm damage. Additionally, intensive (but sustainable) silviculture could produce greater forest biomass amounts, which can replace products and energies with greater climate impacts in the long-term (e.g. Matthews et al. 2015).

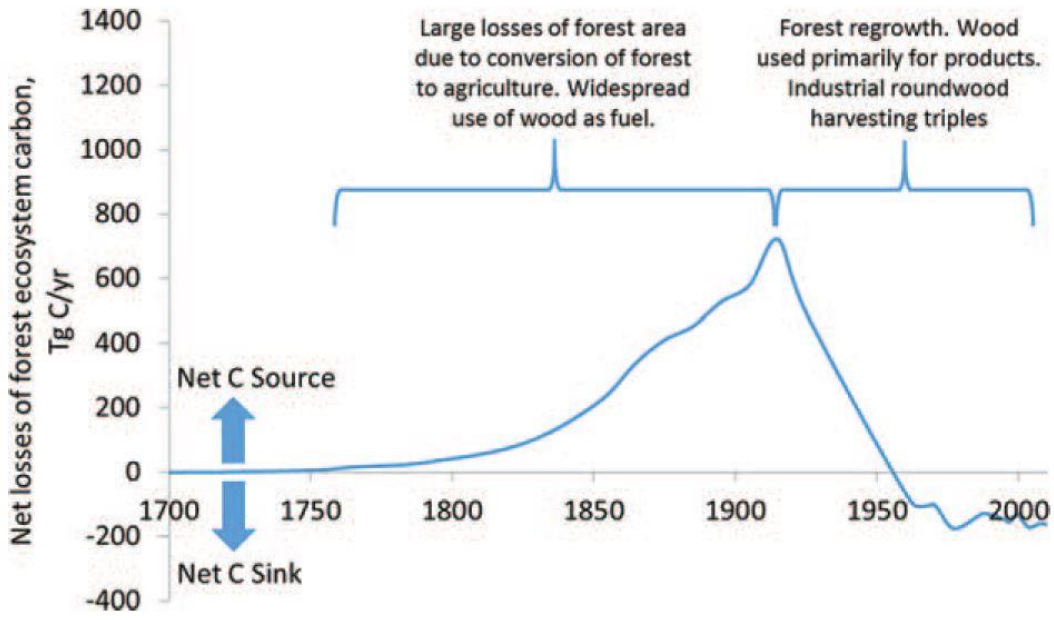


Fig. 15. Carbon balance development in the United States from 1700 to 2010, and central reasons for change (Miner et al. 2014).

A central question is how to value short- and medium-term negative impacts on the climate and long-term climate benefits in relation to each other when aiming for climate change control. To consider the answer to this question economic modeling can be also utilized. The modeling can systematically value the climate benefits and disadvantages at various moments in time.

Current knowledge can offer no unambiguous answer to the abovementioned question. The IPCC (2013) report suggests a link between cumulative emissions development and the earth's temperature (see Fig. 5). In this case the short- and medium-term negative impacts on the climate caused by the use of biomass compared to the use of fossil fuels may not be critical to the climate, as new growth can fix the carbon released into the atmosphere back into vegetation in the long-term. Carbon sinks and removal of atmospheric carbon dioxide are also required in the future (compare Figs. 4 and 5). On the other hand, applying a precautionary principle supports the idea that atmospheric carbon dioxide emissions should not be increased for decades over upcoming decades. Therefore the surest way of working for climate change mitigation is to produce wooden products that cause the least possible total greenhouse gas emissions even in the short-term.

Society's aspiration towards low-carbon is also connected to the time horizon. The substitution benefits of wood products and forest energies change with time. For example, justifying forest energy utilization over fossil fuels for attaining long-term climate benefits will become more difficult in the future following the development of other renewable and nearly emission-free energy production mechanisms (Agostini et al. 2013). Attaining climate benefits through forest energy is justifiable in the mid-21st century, if at least part of the forest energy is produced using the carbon capture and storage (CCS) technique (van Vuuren et al. 2011, IPCC 2014). On the other hand, utilizing wood products (e.g. nanopulp) can help to obtein significant climate benefits in the future, e.g. by replacing steel utilization.

To summarize, additional utilization of forests is best justified with climate reasons if additional utilization replaces products with large life-cycle emissions (e.g. cement, steel) and wood carbon content can be kept in usage for an extended period. The wood carbon content would be directed into energy production only in the discarding stage. In this way climate benefits may be visible even in the short-term. Applying the same principles can help improve the climate impacts of current forest utilization. However, this requires a more in-depth examination, as the calculations involve difficulties and the technological development of novel products that will alter the substitution benefits of wood products in the future.

5. CLIMATE NEUTRALITY AND CLIMATE IMPACTS

Climate neutrality is a wider concept than carbon neutrality, taking into account other anthropogenic climate factors also, in addition to traditional greenhouse gas emissions. The Finnish Climate Change Panel (Seppälä et al. 2014) defined climate neutrality as a condition, where the net impacts of human actions on climate change are zero at a pre-defined time period. Thus, climate neutrality is a condition, where the total cumulative radiative forcing of various components (e.g. greenhouse gas concentrations, aerosols, albedo) causing radiative forcing is zero at a pre-defined time period.

From the viewpoint of climate neutrality, the climate effects of wood utilization and harvest scenarios can be calculated using the following equation, in a similar manner as carbon neutrality:

$$\Delta I = I_u - I_r \quad (2)$$

ΔI is the induced cumulative change in net radiative forcing compared to a pre-chosen reference condition during time period t_1-t_0, Iu is the cumulative radiative forcing according to the tree harvest and utilization scenario, and I_r is the cumulative radiative forcing according to the reference scenario. Radiative forcing calculations can be conducted using separate models recommended by the IPCC (see e.g. Monni et al. 2003, Holmgren et al. 2006).

The carbon neutrality of forest utilization related to the impacts of the GHG emissions at a certain time period does not equate to utilization being climate neutral during this same time period. Including aerosols and albedo in the examination may weaken or improve the climate impacts of forest management. Silvicultural practices affect the ability of forestland to reflect solar radiation (albedo). Clear-cutting, among other practices, increases the escape of radiation energy to space during both summer- and wintertime, i.e. the albedo increases. The average impact over a year is that the albedo of deciduous forests and clearings is greater than that of a coniferous forest. On the other hand, silviculture also affects the formation of climate-cooling aerosols by altering the number of clearings, age structure, and tree species relations. In light of current knowledge, the deciduous stands in more lush sites increase aerosol formation. According to current knowledge, all these factors considered coniferous trees cool the climate less than deciduous trees, despite more carbon dioxide fixing especially in spruce forests during the rotation period. However, a fair amount of uncertainty is involved in forest albedo and aerosol research, and the scientific knowledge of these matters will increase in the future.

Particulates and black carbon emissions are formed during improper combustion conditions. They also affect the climate impacts of wood combustion and the discussion related to its climate neutrality. Particulates are climate-cooling emissions. Black carbon emissions on the other hand affect the albedo of snow and warm the climate. Both the effects of black carbon and particulates can be affected by improving the filtration of the impurities formed in the combustion gases during wood burning and by improving the combustion conditions. Concentrating wood combustion in efficient power plants can minimize the disadvantages of wood combustion. Cost-effective ways of decreasing the emissions of particulates and black carbon are more limited in small-scale wood combustion. Wood pellet usage may improve the situation. The Finnish Climate Change Panel has previously published a report on the climate viewpoints of particulates and black carbon (Laaksonen et al. 2015).

6. INTERNATIONAL AGREEMENTS CONCERNING THE CLIMATE IMPACTS OF FOREST UTILIZATION

6.1 Baseline

Approximately 10% of the world's greenhouse gas emissions are caused by deforestation and forest degradation. Deforestation is a problem particularly in Brazil, Indonesia, Malaysia, and all other poor nations around the equator. On the other hand, the forest resources of rich nations and China have generally been growing since 1990. These countries cause the majority of all greenhouse gas emissions.

This abovementioned baseline cannot be ignored in light of future climate negotiations. Many parties will not be pleased with rich nations being able to fully compensate their fossil fuel emissions with forest sinks.

It is unrealistic that forest energy utilization should have its own emissions coefficients, as current calculation rules for the LULUCF sector for the second commitment period from 2013 onwards, defined in Durban, already gives sufficient theoretical background to assess the emissions impacts of greenhouse gases caused by deforestation, forest management, and forest utilization at the country-level on a yearly basis. Gaining enough background information from various nations for compiling these assessments is the greatest problem. In this sense the OECD nations, Finland and Sweden in particular, are in a very different situation compared to developing nations.

The abovementioned does not mean that the rules for current UN climate agreement LULUCF sector should be changed. Most researchers who responded to the questionnaire used by this report, would be willing to change the rules so that forest sink changes would be included more strongly in the emissions targets than currently (Saikku 2015). Recent scientific knowledge, observing that the increased release of forest biomass carbon into the atmosphere through e.g. energy production does not necessarily lead to short- or medium-term climate benefits, is particularly problematic. This also applies to all nations where forest carbon sinks are growing. More accurate follow-up of forest carbon sinks can also be seen as a way of evading the emissions coefficients imposed on wood energy utilization.

6.2 Current rules

The Durban convention (2011) agreed that each party having ratified the second commitment period of the Kyoto protocol must calculate their sinks and emissions caused by silvicultural practices using the so-called comparison level technique. The comparison level describes the forecasted, average forest sink or emissions to which the actual development of the commitment period is compared. The agreement defined the yearly sink caused by Finnish silviculture at 19.3 million tons CO2-eg (-20.5 million tons CO2-eq when including wood products). The sink benefit gained from silviculture will be regulated using an upper limit. In Durban this upper limit was determined as 3.5% of the total emissions in 1990 (the total emissions of Finland were ca. 71 million tons CO2-eq.). A country will gain compensation according to its upper limit if its sinks are greater than the comparison level. Finland's yearly upper limit during the next commitment period is ca. 2.5 million tons CO2-eq. Finland will gain this benefit in full, once its forest sink is at least -21.8 million tons CO2-eq. The upper limit is one-sided, so no limit has been set for a potential burden gained from the sink (i.e. the sink is smaller than the comparison level).

Durban dismissed the possibility of compensating forestland decrease by a silvicultural sink, which was an option in the first commitment period of Kyoto. At the time of signing the Durban agreement, Finland's emissions related to this were ca. 4 million tons CO2-eq/year. At the time, the Finnish Forest Research Institute (Metla) estimated that ca. 20 000 ha of forestland per year would be transformed into other land use forms. New research estimates this deforestation level at half of the original estimate, i.e. 10–11 000 ha/year until 2040. Approximately 50% of the emissions will be caused by forests transforming into constructed land (buildings, roads, power lines, etc.), 28% will be caused by transformation to agricultural land, and 10% from transformation to peat production. Concurrently the change is estimated to be ca. 3500 ha/year for active and passive afforestation (Haakana et al. 2015).

Currently during the second commitment period of the Kyoto protocol, party nations can calculate their wood products (HWP) as part of their silvicultural greenhouse gas balance. They can also transfer areas experiencing exceptional, human-independent natural destruction (forest fires, insect and pest damage, extreme weather events etc.) outside of the calculation frame.

Current LULUCF sector rules appear to enable the wood utilization increase in Finland in accordance to Finland's climate and energy strategy. This can occur until midway through this century without endangering the country's forest carbon commitment (Fig. 12). It should be noted that the current forest carbon sink commitment in accordance to the Durban agreement is valid until 2020.

6.3 Viewpoints on accounting rule changes and their effects on Finland

The Finnish Climate Change Panel believes that the current knowledge base does not allow the uniform defining of new emissions coefficients to forest biomass energy utilization, which would comprehensively consider the emissions of the land use sector. This is not even desirable, as wood combustion emissions are included in the emissions reporting of the UNCCC's so-called AFOLU (= Agriculture, Forestry and Other Land Use) sector and in the emissions reporting of the LULUCF sector. Reporting in accordance with the Kyoto protocol is more in-depth than UNFCCC reporting, and currently it also includes the emissions from wood products. A shortcoming in the Kyoto protocol calculations is that they do not consider the emissions effects of imported wood originating from outside of the countries having ratified the protocol. However, it can generally speaking be said that current wood combustion emission coefficients and the calculation rules for international agreements concerning the land use sector give good basis for the international assessment of forest utilization greenhouse gas emissions. It is more a question of how this instrument is applied so that the information gained from it can guide climate change control by observing scientific and just viewpoints in the correct way. It is also about political guidance measures in various countries not corresponding to the principles of the international calculation rules.

Year 1990 is the comparison year for the emissions effects of forests in the international agreement practice. The international reduction goals for energy-based emissions are tied to this year. The current Kyoto protocol agreement (2013–2020) has agreed that forest carbon sinks in the developed nations should be maintained at the 1990 level. This is a political decision, which does not attempt to reduce the amount of atmospheric carbon dioxide released from wood utilization. It also does not affect the wood utilization of developed nations, as long as their wood utilization levels settle within the sink obligation frame agreed to at Durban. In this case, forest greenhouse gas emissions forests do not increase in relation to the reference point. On the other hand, the mitigation potential of forests are also not be promoted in developed nations.

It is possible that the emissions goals of the EU climate and energy policy will be broadened to include the CO2 emissions of land use and silviculture (European Council 2014). This offers the opportunity of utilizing forests in a cost-efficient manner to control climate change. How the structural division of the sector will be carried out into the land use sector and non-emissions trading sector is a notable aspect. Similarly, the division of the emissions reduction goals among the nations will be a key question. If the land use sector and non-emissions trading sector (e.g. the methane and nitrous oxide emissions from traffic and agriculture) form a joint emissions reduction –sector, it would be possible for Finland to strive for cost-efficient ways to decrease their emissions using their carbon sinks. On the other hand, the future development of forest carbon sinks contains significant uncertainty (see section 2.3).

The current system does not encourage the increase of forest sinks, even though this might be a cost-efficient way of producing short-term climate benefits. As upper limits have been assigned in relation to the total emissions of individual nations, the lack of incentives is particularly clear in economically small, but forest resource –rich nations such as Finland. A system that limits the utilization of forest carbon sinks, so that the limited portion of the carbon sink could always be credited, would encourage nations to increase their carbon sinks.

7. RESEARCH NEEDS

The research needs for understanding the climate impacts of forest utilization can be divided into two main groups:

a) Forming a general view of the integral questions, which would help in understanding the magnitude and time scale of various processes and actions
b) Scientific research focusing on special questions in fields where scientific knowledge is lacking or scarce, and that are considered important for seeing the big picture.

The baseline should be that these research lines should interact better with each other than currently. This is also the case with the interaction between various research groups. Forming an overall framework based on the natural sciences and economically sound modeling should be the objective. This framework should receive all necessary initial data and modeling foundations from results attained from research focusing on the special questions. Formal modeling is essential in this case, as it offers the tools for the transparent processing of assumptions related to central forest-product-climate-impact -relationships.

The questionnaire sent out to professionals, executed at the start of the project, revealed that professional opinions still differ from each other when considering the various roles of forests in climate matters (Saikku 2015). Narrowing these differences is not easy, even through fact-based research results. The essence of the differences is related to theoretical dissimilarities in terminology. Professionals often utilize a heuristic problem-solving approach, which may be based on informal deduction and the usage of intuition in situations that do not represent the core competence of the professional.

The additional benefits provided by modeling economic and product –related effects are an apparent baseline for research, on top of the natural sciences model framework. The abovementioned modeling affords the opportunity to incorporate basic cost and well-being assessments into climate change, enabling cost-effectiveness assessments and policy planning of policy instruments (Lintunen and Uusivuori 2015).

To develop encompassing models, we should form a multidisciplinary research consortium in Finland, which should work in close interaction with other international research groups. It would define the types of questions that the model should be able to clarify to some extent.

The following short-term focal research needs have arisen through the assessment:

- It is currently unclear how large carbon sinks Finland can uphold in the long-term. Research should compare the baselines and differences of various models and include all factors centrally influencing Finnish forest sinks (wood utilization and utilization needs of various products, stand age class distribution, changing growth/climate conditions (soil respiration and temperature increase, nitrogen and other nutrients, carbon dioxide concentrations, damages and forestry management practices).

- Future forest-based bioeconomy should be able to respond to the challenges caused by climate change. Research examining the best wood utilization targets in terms of climate change mitigation should envelop current and to-be-developed products and forest energy as part of the total energy production.

- The climatic external impacts of forests, such as the enabled carbon sinks, and their utilization should be considered more carefully in the planning and execution of policy instruments. This requires the creation and utilization of a comprehensive scientific-economic model framework that accurately describes processes.

8. SUMMARY AND CONCLUSIONS

The carbon stock of tree stands and forest soils is growing in Finland, i.e. forests act as carbon sinks. A carbon sink means that forests sequestrate carbon dioxide from the atmosphere, and thereby our forests cool the climate. In light of recent studies and scenario runs, it strongly appears that Finnish forests will remain notable carbon sinks also in the near future. The positive situation with the carbon sinks is a consequence of the forest age class structure, of harvest amounts being clearly smaller than tree growth, and of increased growth caused by nitrogen deposits, increasing atmospheric carbon dioxide concentrations, and the temperature among other factors.

The results of various model examinations show the relationship between increasing harvesting and sink development to vary. According to MELA model examinations carried out by the Natural Resources Institute Finland, the Finnish forest carbon sink is estimated to grow over the next decades, even if forest utilization were to increase somewhat from its current level. The future of carbon sink development is difficult to estimate for the second half of this century. Climate change and its consequences, and the future utilization rate cause uncertainty in the estimates.

Carbon neutrality of forest raw material usually means that the carbon debt created in forests after harvest has recovered as a result of carbon sequestration by new growth. Carbon released during harvest is fixed back into the vegetation at the stand-level, in accordance with the rotation period used. This rotation period varies greatly depending on the site and tree species. In addition to stand growth, the volumes of various wood use forms affect how the carbon balance develops at the national level. Harvests slow down carbon stock growth. As only a small part of Finnish forests are managed per year, the carbon balance of the entire forest area does not show a carbon debt caused by harvests, but the forest carbon stock is growing.

The recovery rate of the harvest-created forest carbon debt sets the baseline for examining the climate effects of biomass exploitation. This climate debt is formed from forest growth and the storage time of product-fixed carbon. The climate impact assessments of wood products and forest energy must also consider the attained substitution benefits when they are used to replace alternative products and energies. The comparison must consider the life cycle greenhouse gas emissions of products and energy forms. The climate impacts and potential climate benefits of wood products and forest energy change with time. The actualization of climate benefits at a given time indicates a temporal turning point, where the greenhouse gas effects of wood products and forest energy utilization on climate change are smaller than those of competing products and energies.

Assessment of the climate impacts of wood products and forest energy are affected by the calculation methods and reference points to which carbon balance change caused by forest utilization is compared. Various studies have used different calculation methods and reference points, which causes confusion when compiling conclusions concerning the climate impacts of wood products. Stand-level assessments formulate the climate impacts of single actions, while nation-level assessments clarify how forest utilization level changes affect climate impacts. The reference point, where forest carbon balance development occurs without harvests, equates to a natural state when assessing human actions and their impacts on the climate. However, it is more a question of political choice, if forest carbon balance returning to pre-harvest levels is set as the baseline. In this case, the efficiency of climate change mitigation practices are assessed in relation to a certain acceptable reference point. This has so far also been the baseline for the international climate agreement.

Model comparisons, contrasting the change in forest utilization levels to the current situation, show that increasing forest utilization from the current level does not create short-term (10–30 years) climate benefits in forest industry production activities and energy usages similar to current ones. The climate benefits even in the mid length-term (50–100 years) remain unsure, despite the climate sink continuing to grow after increased harvesting. The smaller forest carbon sink, due to increased harvests, compared to a reference point, where forest utilization does not increase, is the main reason for the delay in climate benefits from additional forest utilization. The carbon sink loss is clearly greater that the carbon amount channeled through increased harvests into economic usage.

The wood carbon taken from forests, apart from construction utilization, is usually released in less than 20 years. In energy utilization, wood fuel usage clearly released more carbon dioxide emissions per created energy unit than fossil fuel usage. Additional forest utilization leads to an increase in atmospheric carbon dioxide emissions. Because of slow tree growth, repairing this increase with the carbon fixing of new growth requires a long time in Finland. Climate change control would concurrently require significant short-term (10–30 years) reductions in greenhouse gas emissions. Increased harvests do not support this goal, and a greater climate benefit would potentially be reached in the medium-term by refraining at current industrial wood harvest rates and by increasing the carbon sink. On the other hand, intensive (but sustainable in size) forestry could produce larger forest biomass quantities, which in the long-term could replace products and energies causing greater radiative forcing. Studies do not provide a clear picture of how the short- and medium-term negative impacts on the climate caused by forest utilization are set in relation to the climate benefits attained in the long run when aiming for climate change control.

The use of wood can be best argued on the basis of climate reasons, when a wood product can replace a product with high greenhouse gas emissions (with the whole product chain taken into account), and its carbon content can be stored for a long time, and finally, it is used for energy purposes. This would attain climate benefits even in the short-term. Increased wood energy use creates climate benefits even in the short-term, if rapidly decomposing logging slash and thinning trees smaller than industrial wood are used rather than stemwood. However, their utilization amounts are fairly small. Climate benefits in the short-term can be gained from afforesting both wasteland and fields left outside of agricultural use. Replacing fossil fuels with forest energy creates climate benefits in the long-term.

Society’s aspiration towards low-carbon conditions and technological developments with novel products changes the substitution benefits of wood products and forest energies in the future in relation to alternative products and energies. Attaining climate benefits through forest energy is more difficult in a low-carbon world of the future. On the other hand, utilizing novel wood products (e.g. nanopulp) can attain greater future climate substitution benefits in relation to e.g. steel.

In addition to carbon balance development, trees also influence the climate through the albedo (the proportion of reflected sunlight) and aerosol effects. Through tree species selection and forest management practices both forest albedo value and aerosol formation could be influenced. However, currently it is too early to say the total climate impact of albedo and aerosol effects of Finnish forests. These along with wood burning particulates and black carbon emissions should be considered when discussing climate impacts of forests and forest use. Studies suggest that considering just the climate impacts of carbon does not guarantee the best possible forest management and use for the climate.

The current climate agreement compares emissions reduction actions to the emissions of 1990. Concurrently, forest carbon sinks in developed nations are trying to be kept at the 1990 level. Emissions released during forest utilization, and their effect on carbon sinks are reported in the land use sector (LULUCF), the emissions segment of which is nearly 10% of the greenhouse gas emission estimates for the entire world. Current forest sector emissions are created particularly in tropical regions following deforestation. Halting this destruction is the first target in climate change control focusing on the international land used sector. Progress has been made during previous years. If future climate agreements treat and report forest utilization and carbon sinks in a way similar to current conditions, the model examinations uniformly show that the increased use of wood chips, planned in the climate and energy strategy of Finland, does not endanger the nation’s political climate goals from being realized, at least in the short-term. These model examinations have shortcomings, which can be seen in the growing uncertainty related to carbon sink development estimates when moving further away from the current time.

The rules of the current climate agreement do not encourage to build up the forest carbon sinks. There is a need to develop incentives for carbon sinks, however, it should not be allowed to lead to a general lessening in fossil fuel emissions reduction willingness.

For the future, it would be important to support multidisciplinary research for investigating the climate impacts of forest utilization. This should aim at gaining a clear general picture, while integrating research focusing on special questions. In addition to climate aspects, the assessment framework should contain economic and social effects along with other environmental aspects.

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