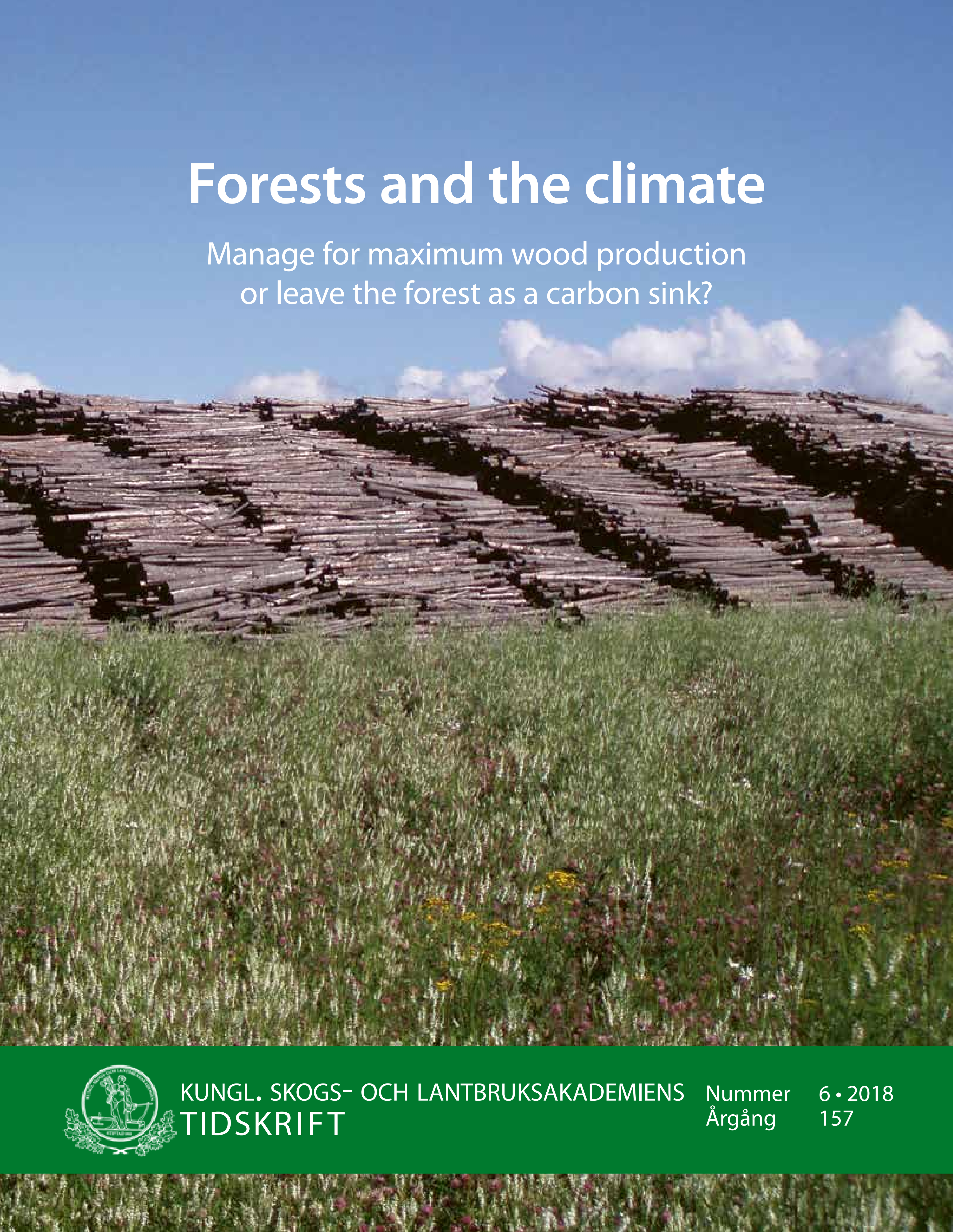

Forests and the climate

Manage for maximum wood production
or leave the forest as a carbon sink?

KUNGL. SKOGS- OCH LANTBRUKSAKADEMIENS
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Forests and the climate

Manage for maximum wood production or leave the forest as a carbon sink?

Report from a conference held on March 12–13, 2018, in Stockholm Sweden, organized by the Royal Swedish Academy of Agriculture and Forestry, the Royal Swedish Academy of Sciences, and the Royal Swedish Academy of Engineering Sciences

KUNGL. SKOGS- OCH LANTBRUKSAKADEMIEN

Contents

Preface

The Paris Agreement promotes the role of forests as being critical for achieving the central goals of maintaining the global temperature rise this century to well below 2 degrees Celsius above pre-industrial levels, and to limit the temperature increase even further to 1.5 degrees Celsius. In this respect, forests are important because they are large carbon sinks that absorb one-quarter to one-third of greenhouse gas (GHG) emissions from the atmosphere. However, forests are also sources of the carbon that is released when, for example, trees die and decay or burn in forest fires. How we manage the forests and use forest products also affects the carbon balance. The issues dealt with in this report relate to the management of our forests so as to obtain the best outcome for the climate, while at the same time ensuring that we create sustainable and healthy, multi-purpose forests. Although the report has a global perspective, most of the examples given are in the context of Europe, with special reference to Sweden.

This report aims to provide a broad overview of the complex role of forests in mitigating GHGs, as well as defining the key disagreements that exist between scientists regarding the consequences for the carbon balance of different forest management methods. While science has come a long way in understanding the role of forests and the consequences of different management methods for climate change, it is fair to say that rather than clear results and solutions emerging, more questions have been raised. More research and more discussions are needed. As leading scientists from different parts of the world meet to learn from each other, the probability of finding optimal solutions increases.

The *Forests and the climate* conference is an example of strong collaboration between the Royal Swedish Academy of Agriculture and Forestry (KSLA) – where the Committee for climate and land use towards 2030 has been responsible for the work, the Royal Swedish Academy of Sciences (KVA), and the Royal Swedish Academy of Engineering Sciences (IVA). Such collaborations are valuable when important questions need to be addressed from different perspectives and when a combined effort is more fruitful than individual efforts. Sweden, which is a forest nation covered to about 70 percent by forests, has a strong interest in matters related to forest management and forest well-being. The forest is close to our hearts as well as to our economy. Many citizens have strong opinions on forest issues, so it is vital that we have high-level research and excellent scientists dealing with the complex issues pertaining to the role of forests in climate change mitigation.

It is our fervent hope that the conference and the present report will serve to enlighten and to increase understanding of the complex relationship between forests and the climate. We need the best knowledge available in the crusade against climate change, to develop evidence-based recommendations for decision makers and forest owners, as well as to define the gaps in knowledge that need to be filled in order to meet the Paris Agreement goals.

Lisa Sennerby Forsse
President of KSLA

Dan Larhammar
President of KVA

Carl-Henric Svanberg
Chair of IVA

Executive Summary

In order to meet the goal of the Paris Agreement, greenhouse gas (GHG) emissions must be reduced urgently. This will entail transformation of all the major sectors of society. All available measures and technologies must be considered, including the ramping up of energy conservation and efficiency measures and investments in renewable energy technologies, the substitution of GHG-intensive materials and improving the efficiency of material use (including a transition from linear to circular material flows), enhancement of carbon removal by land sinks, and the development of carbon capture and storage (CCS) technologies, to be applied to both fossil fuels and bioenergy, as in the case of bioenergy combined with carbon capture and storage (BECCS).

This report summarizes the discussions that took place at a 2-day international conference titled *Forests and the climate: Manage for maximum wood production or leave the forest as a carbon sink?*, held on March 12th–13th at the Royal Swedish Academy of Agriculture and Forestry in Stockholm, Sweden. The conference aimed to facilitate dialogue among experts representing different viewpoints related to forest management and climate change mitigation, with the goals of: 1) clarifying why experts who accept the same evidence draw very different conclusions concerning the influences of forests and forest management on the climate; and 2) identifying knowledge gaps and priorities for future research and data collection.

The invited presentations and open discussions addressed forest management, forest-climate interactions, and the potential roles of forestry-derived feedstocks in the energy and material systems. All of these issues were discussed in the context of the transformations that are required to reach the targets set out in the Paris Agreement on climate.

The conference was structured around questions identified as crucial to the ongoing debate on forests and climate. The discussions and conclusions related to these questions are summarized below.

Is there a difference between biogenic carbon emissions and fossil carbon emissions? Can biogenic carbon balances be omitted from climate impact assessments of forest products and systems?

There is a difference between biogenic and fossil carbon emissions. Biogenic carbon is the carbon that is stored in plants, animals, and the organic matter in soils (the biosphere). It is also stored in biobased products. The biogenic carbon is continuously circulated between the biosphere and the atmosphere; it is removed from the atmosphere through photosynthesis and emitted to the atmosphere through respiration, decay, and fires. Fossil carbon emissions represent a linear flow of carbon from geologic stores to the atmosphere. These emissions are fundamentally different from biogenic carbon emissions.

Nevertheless, it must be emphasized that biogenic carbon should be accounted for in assessments of forest-based mitigation options. Otherwise, the ways in which such mitigation options affect atmospheric GHG concentrations will not be accurately assessed.

What roles will biomass play in the energy system in the short, medium, and long terms?

Biomass is likely to play important roles in the energy system, provided that the associated net GHG emissions are below the limits set in relation to climate targets (naturally, this requirement applies to all energy options). All the IPCC scenarios that meet the targets set by the Paris Agreement include a rapid increase in the share of renewable energy, typically in the form of power generation using biomass, wind, and solar sources. Several scenarios strongly rely on a biomass-based energy supply, especially in relation to its potential to generate negative emissions. Balancing technologies are needed to ensure power stability and quality and to maximize the value of solar and wind power generation. Therefore, the value of dispatchable power based on biomass is likely to be high, at least in the 2050 timeframe.

Furthermore, carbon-based transportation fuels will remain important in the decades to come, as electrification of the transport sector will take time to reach its full potential. The use of biofuels for road transportation can facilitate reductions in the use of fossil fuels during the transition period. In the longer term, biofuels are likely to be primarily used in applications where the substitution of carbon-based fuels is particularly difficult, such as in aviation and long-distance ship transportation. Biomass may also be increasingly used in BECCS applications, to establish net-negative GHG emissions. However, BECCS will compete with other uses of biogenic carbon (e.g. transport and materials) and the potential future availability of BECCS should not be used as an argument for postponing near-term actions.

How can forest materials substitute for GHG-intensive materials and reduce their GHG footprints?

The production of basic materials, such as steel, cement, aluminum, and plastics, accounts for a large proportion of global GHG emissions. The emissions from such industrial activities can be reduced through: 1) changing the resource use in industrial processes (e.g. improving conversion efficiency and shifting from coal to biomass to produce process heat) and transitioning from linear to circular material flows; 2) changes in lifestyle and consumption patterns; and 3) material substitutions. Biobased materials can substitute for basic materials in many applications, for example, replacing cement with wood in construction or using carbon fiber as a substitute for steel. In addition, the use of biobased plastics, chemicals, clothing, and packaging could be increased. Innovations in both technologies and policies are essential for the necessary developments to take place. As for energy applications, the net reduction in GHG emissions associated with biobased materials needs to be substantiated.

What are the trade-offs between biomass production, carbon sequestration, and storage of carbon in forests and forest products? How do these trade-offs pertain to different climate change mitigation objectives?

Forest management decisions reflect the balancing of economic, ecological, and social objectives. In relation to the objective to mitigate climate change, the forest management system needs to consider the contributions from forest carbon sinks, carbon storage in forests, and wood harvesting, to produce forest products that substitute for fossil fuels and other products. There are apparent tradeoffs between these objectives. A reduction of the forest carbon stocks has the same instantaneous effect on the atmospheric CO_2 concentration as an equivalent level of carbon emissions arising from the use of fossil fuels, cement, etc. Thus, it decreases the net GHG savings associated with forest product use. Forest management to enhance wood production can lead to both increases and decreases in forest carbon stocks. The actual outcome depends on geographically varying factors, such as the state of the forest (e.g. species and age structure), climate, and the types of management measures that are employed.

Any expansion of the use of bioenergy and biobased materials must be accompanied by sustainable forest management principles that safeguard against systematic overharvesting that would entail losses of forest carbon stocks and sink capacity, as this would jeopardize the GHG emissions savings, as well as the future wood production capacity. Accounting frameworks need to be developed and applied rigorously, to ensure that the GHG benefits of different types of substitution can be substantiated in an accurate manner.

Instead of increasing biomass production to produce more forest products, forest owners may choose to harvest fewer trees and give priority to carbon storage in the forest. Such a strategy could provide greater net GHG savings and reduce the rate of warming over a period of time (decades). At the same time, the contribution of the forest sector to the necessary transformation of the major sectors – through material substitution and bioenergy replacing fossil fuels – would be lower if fewer forest products were produced. The strategy may also steer development towards an end-point where forests store more carbon but have a lower capacity to produce biomass for various uses. This contrasts with a strategy that aims to maintain net forest growth at a high level to allow sustained harvesting.

What are the differences between rotation forest management and selection forest management in relation to carbon balances and biomass production?

It is difficult to compare the carbon balances of rotation forest management and selection forest management. In boreal countries with a well-established forest industry, humans have shaped the forest by employing rotation forestry systems with even-aged forest stands. When a stand is harvested, the carbon balance is switched abruptly from carbon sequestration to instantaneous biomass carbon removal from the stand. This is followed by net carbon emissions during the regeneration phase and, subsequently, by a rapid net carbon gain in young stands, which declines as the forests become older. A balanced stand age distribution at the forest estate level is often targeted. At this level, the forest carbon stock is more stable and fluctuates around a trend line that can be increasing or decreasing or approximately stable.

An alternative to rotation forestry is selection forestry with uneven-aged, structurally more complex forest stands, a continuously maintained forest cover, and more-limited harvests at shorter intervals. Ground and sub-canopy forms of vegetation are continuously present and utilize the light and nutrient that become available each time the trees are harvested. Site preparation is generally not needed, and the soil carbon losses associated with site preparation are thereby avoided. As for rotation forestry systems, the forest carbon stock fluctuates around a trend line at the forest estate level.

The structural differences between the two management systems make comparisons of carbon balances difficult. One view is that a shift from rotation forestry to selection forestry is likely to result in a lower carbon sequestration rate, at least during a transition period. An alternative view is that there is inconclusive evidence concerning the differences in growth and in standing volume over time. A shift to selection forestry may be motivated for other reasons, such as creating more favorable conditions for recreation, biodiversity, and ecosystem services.

How do different forest management strategies interact with other climate forces than GHGs, e.g. reflection of solar radiation from Earth's surface? Should non-GHG forcers be considered when climate change mitigation strategies are developed for the forestry sector?

Studies have shown that the climate effects of non-GHG forcers can be as potent as those of GHGs. A full assessment of the influence of forests on the climate system therefore needs to consider also non-GHG forcers, including surface albedo, evapotranspiration, surface roughness and the production of biogenic volatile organic compounds (BVOCs) which have an effect on the number and quality of aerosols formed in the atmosphere.

Emissions of biogenic volatile organic compounds (BVOCs), and subsequent formation of secondary organic aerosols, can cause both warming and cooling. The outcome depends on where and when the emissions occur, types of BVOCs emitted, and which aerosols are formed. Deciduous tree species have generally higher reflectivity (albedo) than conifers, which means less warming. The species difference is also important during the snow season since different forest types, including different management stages, also have very different albedo depending on the degree of exposure of the (snow covered) forest floor towards the atmosphere.

Changing species composition in forests by management is a possible climate change mitigation activity. But the net effect of all climate forcers combined is uncertain and location-specific. Few studies have to date included the effects of all relevant processes due to inherent uncertainties and complexity of modelling. More research is therefore needed to advance the understanding of how forest management decisions influence the full range of climate forcers.

While the above conclusions hopefully can guide policymakers in their endeavors, there remain significant gaps in our knowledge, which need to be filled by further research and collaborative activities. The most important issues that should be addressed are:

- The lending of support national, cross-sectoral analyses of the contributions of land use and bio-based systems to reducing the radiative forcing in the atmosphere over various timescales. These analyses should consider all climate forcers, as well as biomass usage in the different sectors.

- The establishment of research programs that expand knowledge concerning the interactions between climate change, human activities, and natural ecosystem processes, such as aging and disturbances. These programs should explore how these interactions will affect non-GHG climate forcers, as well as the capacities of forests and other ecosystems to sequester and store carbon over time. Furthermore, they should address both rotation forestry and selection forestry, and examine the transition from the former to the latter.

- The roles of biomass in different sectors and the effectiveness of different biomass and land uses for climate change mitigation. Many sectors have expectations regarding biomass as a mitigation option. Total biomass demand may exceed what can be made available while maintaining favorable conditions for other social, economic, and ecological functions.

- The development, evaluation, and improvement of methods and tools for monitoring, reporting, and verifying carbon stocks and flows in forests and in forest products. As non-GHG climate forcers can be as important as GHGs, it is desirable to develop also tools that cover these forcers.

The conference focused on climate change mitigation and did not consider important issues related to adaptation and the general need to preserve, restore, and enhance biodiversity and the capacities of forests to support a multitude of ecosystem services. Nonetheless, *there is a need to create and expand scientific and policy collaborations among boreal countries, to address both mitigation and adaptation issues*. The boreal countries face serious consequences of climate change and there is much to be gained from expanding collaborative research activities to assess and address the impacts of climate change. The International Boreal Forest Research Association (IBFRA) can serve as a vehicle for advancing this research agenda.

Introduction to the conference and the report

This report summarizes the discussions from a 2-day international conference titled *Forests and the climate: Manage for maximum wood production or leave the forest as a carbon sink*. This conference took place on March 12th and 13th, 2018 at the Royal Swedish Academy of Agriculture and Forestry in Stockholm, Sweden.

The conference built on earlier events on the same topic organized by the Royal Swedish Academy of Sciences (KVA) and the Royal Swedish Academy of Agriculture and Forestry (KSLA), and most recently a roundtable discussion of the European Academies' Science Advisory Council (EASAC) report titled *Multi-functionality and Sustainability in the European Union's Forests*, which was launched in mid-2017.[1]

The conference aimed to facilitate dialogue among experts representing different views related to forest management and climate change mitigation, to help advance scientific understanding. Another objective was to identify knowledge gaps and priorities for future research and data collection. The invited presentations and open discussions addressed forest management, forest-climate interactions, and the possible roles of forestry-derived feedstocks in the energy and material systems. All of these issues were discussed in the context of the transformations required to reach the targets of the Paris Agreement on climate.

This report is an attempt to summarize the outcomes of the discussions at the conference, bearing in mind that the authors of the report are solely responsible for its content and conclusions. The report is structured around a number of key questions (see *Background*) that prior to the conference were identified as crucial to the ongoing debate on the role of forests and the forest sector in climate change mitigation.

The conference program is provided in Appendix 1 to this report. Presentations and supporting documents can be found at *www.ksla.se/aktivitet/forests-and-the-climate/*.

We are grateful to the conference speakers and other experts who contributed to the preparation of the supporting documents before the conference. We especially thank those who gave presentations at the conference and who carefully reviewed draft versions of this report. In addition, we thank Elin Mellqvist (KVA) and Birgitta Naumburg (KSLA) for providing administrative support for the conference implementation, as well as for the production of this report. Finally, we send our thanks to all the conference participants who contributed to important discussions during the conference (see Appendix 2).

We are also very grateful for the financial support received from the Swedish Foundation for Strategic Environmental Research, Mistra, the Swedish Research Council Formas, the Swedish Energy Agency, and Chalmers University of Technology.

Stockholm, December 2018

Göran Berndes, Mattias Goldmann, Filip Johnsson, Anders Lindroth, and Anders Wijkman
The Editorial team

1. *https://easac.eu/meetings-events/details/launch-of-easac-report-on-sustainable-forests/*.

Background

Key questions

The report is structured around a number of key issues that prior to the conference were identified as crucial to the ongoing debate on the role of forests and the forest sector in climate change mitigation. They are discussed here in the following order:

1. Is there a difference between biogenic carbon[2] emissions and fossil carbon emissions? Can biogenic carbon balances be omitted from climate impact assessments of forest products and systems?

2. What roles will biomass play in the energy system in the short, medium, and long terms?

3. How can forest materials substitute for GHG-intensive materials and reduce their GHG footprints?

4. What are the trade-offs between biomass production, carbon sequestration, and storage of carbon in forests and forest products? How do these trade-offs pertain to different climate change mitigation objectives?

5. What are the differences between rotation forest management and selection forest management in relation to carbon balances and biomass production?

6. How do different forest management strategies interact with other climate forces than GHGs, e.g. reflection of solar radiation from Earth's surface? Should non-GHG forcers be considered when climate change mitigation strategies are developed for the for-estry sector?

While many of the examples cited are related to Europe and part of the text specifically concerns Sweden, the report has a global scope.

Forests and the Climate

The conference was set against the background of the Paris Agreement from 2015, which aims to restrict the increase in the global average temperature to *well below 2˚C relative to pre-industrial levels* and pursues efforts to limit the temperature increase to 1.5˚C above pre-industrial levels (see box next page). This will require a comprehensive portfolio of technologies and policy measures modify and replace production and consumption systems in society. Most of the countries that have submitted Nationally Determined Contributions to the UNFCCC secretariat have indicated that land use, and in particular forestry, will play an important role in achieving the desired reductions in GHG emissions. At the same time, reference to land use is often vague and non-specific, which indicates that countries have yet to develop mitigation strategies (including monitoring and reporting tools) with regard to land use.[3]

Around the world, forests act as large carbon sinks that remove about one-quarter to one-third of anthropogenic GHG emissions from the atmosphere

2. Biogenic carbon is the carbon that is stored in animals, plants, and organic matter in soils (the biosphere) and in biobased products, such as wood-frame buildings, paper, food, and biofuels. Carbon is continuously circulated between these biogenic carbon pools and the atmosphere. It is removed from the atmosphere through photosynthesis and emitted to the atmosphere through respiration, decay, and combustion. Carbon is also transferred between different biogenic carbon pools. For example, carbon in vegetation is transferred to soils through litter fall. When a tree is harvested and used to produce sawnwood for the building industry, carbon is transferred from the forest into the building.

3. Grassi G. & Dentener F. 2015. Quantifying the Contribution of the Land Use Sector to the Paris Climate Agreement. Report No. EUR 27561, doi: 10.2788/096422. Publications Office of the European Union.

The Paris Agreement consists of 29 Articles, of which the following are particularly relevant to our case:

Article 2: … Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change…

Article 4: In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible… and to undertake rapid reductions thereafter in accordance with best available Science, so as to achieve a balance between anthropogenic emissions by sources and removal by sinks of greenhouse gases in the second half of this century… All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies, mindful of Article 2 and taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Article 5: Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d), of the Convention, including forests…

Article 10: Parties share a long-term vision on the importance of fully realizing technology development and transfer in order to improve resilience to climate change and to reduce greenhouse gas emissions.

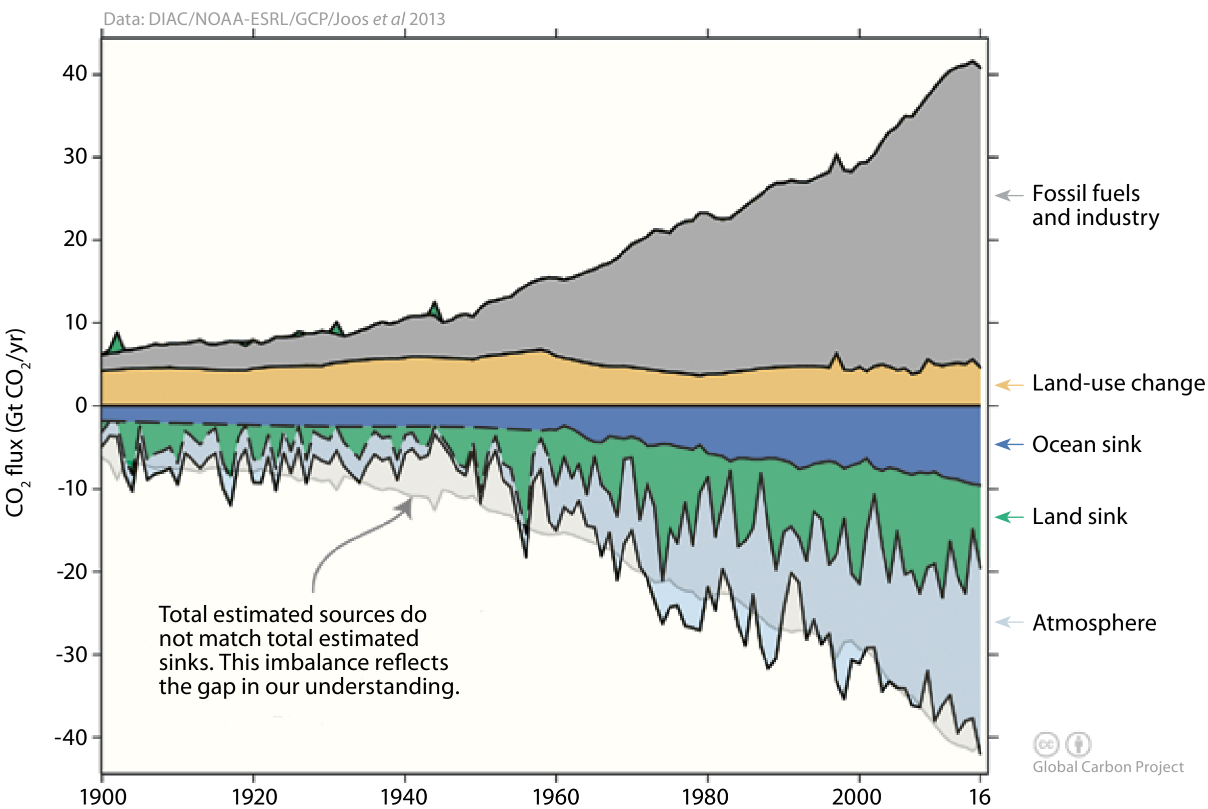

Figure 1. Carbon emissions (positive) are partitioned between the atmosphere and carbon sinks on land and in the ocean (negative). The fossil carbon flow to the atmosphere is much larger than the net flow of carbon from the land to the atmosphere, which is designated as land-use change. Although not depicted in this diagram, the bi-directional carbon flows between the land and the atmosphere (which are driven by photosynthesis and respiration) are one order of magnitude larger than the fossil carbon flow to the atmosphere. These bi-directional flows vary over time, are difficult to quantify, and are expected to be influenced by climate change in ways that are not well understood.

(Fig. 1). However, the efficiencies of these sinks vary between the Northern and Southern Hemispheres and between different forest and management types. Land-owners and forest-based industries play important roles in the global GHG balance. They influence the capacities of forests to sequester and store carbon. In addition, they generate forest products that can store carbon and substitute for fossil fuels and other products, thereby reducing carbon emissions.

Uncertainty prevails with regard to how the interactions between climate change, human activities, and natural ecosystem processes, such as aging and disturbances, affect the capacity of forests to sequester and store carbon over the long term.[4] Furthermore, forests affect the climate by:

- modulating the share of incoming sunlight that is reflected into space (instead of warming the earth surface);
- influencing evapotranspiration, which in turn influences the near-surface temperatures; and
- emitting biogenic volatile organic compounds (BVOCs).

As explained later in this report, the net effect of all the climate forcers combined is uncertain and location-specific, although studies have shown that the effects of non-GHG forcers can be as potent as those of GHGs.

A major concern is that the promotion of bioenergy, and of biobased products in general, could result in a strongly increasing wood harvest, threatening the very existence of forests. Considering the well-documented cases of deforestation and forest degradation around the world, this concern is justified. There is a lower risk of such developments occurring in countries where wood demand incentivizes land owners to keep their land forested and to manage their forests for wood production, and where legislation and sustainable forest management (SFM) principles[5] protect forests and safeguard against overharvesting.

In regions where forest growth rates exceed harvest levels (e.g. in Europe), it is expected that sustainably managed forests can make a substantially larger contribution to energy and material supply than is currently the case, thereby reducing carbon emissions. Nonetheless, forest biomass resources are limited and global application of SFM principles may well lead to a situation where the demand for forest biomass exceeds the supply capacity.

From the above, it can be concluded that:

1. a credible accounting framework is needed to ensure that the GHG consequences of forest management, as well as the use of forest products, are taken into account appropriately;

2. climate forcers other than GHGs need to be considered, as they can have similarly substantial effects on the climate; and

3. in the development of sustainability frameworks for bioenergy and other biobased products, it will be important to ensure that all sustainability dimensions in SFM are considered – not least in a scenario in which biomass demand grows rapidly and prices escalate.

4. Girardin, M.P. *et al*. 2016. No growth stimulation of Canada's boreal forest under half-century of combined warming and CO_2 fertilization. PNAS, doi: 10.1073/pnas.1610156113; Nabuurs, G.-J. *et al*. 2013. First signs of carbon sink saturation in European forest biomass. *Nature Climate Change*, doi: 10.1038/nclimate1853; Baccini, A. *et al*. 2017. Tropical forests are a net carbon source based on aboveground measurements of gain and loss. *Science*, doi: 10.1126/science.aam5962.

5. While this document focuses on aspects related to climate change, sustainable forest management is a broader topic that encompasses environmental, economic, and socio-cultural dimensions. The Ministerial Conference on the Protection of Forests in Europe (FOREST EUROPE) and the Food and Agriculture Organization of the United Nations (FAO) defines SFM as: *The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.*

The remaining carbon budget

A carbon budget is the amount of carbon that can be added to the atmosphere while retaining a certain likelihood[6] of not exceeding a given temperature threshold. It is estimated that the carbon budget that corresponds to a "likely" chance of holding the increase in average global temperature at <2°C above the pre-industrial level is within the range of 590–1240 $GtCO_2$ for emissions after year 2015.[7] As current global annual CO_2 emissions are about 40 GtCO2/yr[8], emissions must be reduced urgently to stay within this budget. Remaining within a 1.5°C budget requires even more drastic reductions in emissions.

The GHG reductions achieved to date – in the EU context, around 20 percent of territorial emissions between the year 2000 and year 2020 – have been achieved relatively easily using present practices and societal structures. However, meeting the Paris Agreement temperature target is a daunting task. Incremental change will not suffice. Instead, what is required is nothing less than transformation of all the major sectors of society.

One issue of major concern is that most of the IPCC scenarios for meeting the global 2°C target include an overshoot of the carbon budget, followed by the removal of excess carbon from the atmosphere – so-called negative emissions – based on large-scale deployment of CO_2 removal technologies. Bioenergy combined with carbon capture and storage (BECCS) is the option that has received the most attention to date. Obviously, the contribution of BECCS is critically dependent upon whether it is possible to meet the associated biomass demand without competing with food production and without causing significant increases in GHG emissions due to the changes in land use, including reductions in the strength of the land-based carbon sink.

This report does not include a comprehensive discussion of the feasibility – and desirability – of large-scale deployment of BECCS to help meet the Paris Agreement temperature targets. Nevertheless, we emphasize that the scale of the biomass supply needed is in itself a strong argument for a more rapid reduction of GHG emissions in the near term, so as to be less dependent on negative emissions in the future. Furthermore, the needed transformations in society will take time to implement and will require a balance between actions taken now and actions to be taken in the future. Therefore, measures to reduce GHG emissions in the near term should, ideally, facilitate additional steps towards accomplishing deeper reductions in the longer term. Measures that instead make future actions more difficult risk being counter-productive in the long-term perspective.

6. The likelihood scale used in the IPCC AR5 includes the following terms to designate the likelihood of an outcome: "Virtually uncertain" (99–100% probability); "Very likely" (90–100%); "Likely" (66–100%); "About as likely as not" (33–66%); "Unlikely" (0–33%); "Very unlikely" (0–10%); "Exceptionally unlikely" (0–1%). Source: Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.-K., Yohe, G.W., Zwiers, F.W. 2010. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change (IPCC).

7. Rogelj, J., Schaeffer, M., Friedlingstein, P., Gillett, N.P., van Vuuren, D.P., Riahi, K., Allen, M., Knutti, R. 2016. Differences between carbon budget estimates unravelled. *Nature Climate Change* 6, 245–252.

8. Estimate for year 2016 by the Global Carbon Project: 40.8 ± 2.7 $GtCO_2$. Source: *www.globalcarbonproject.org/carbonbudget/.*

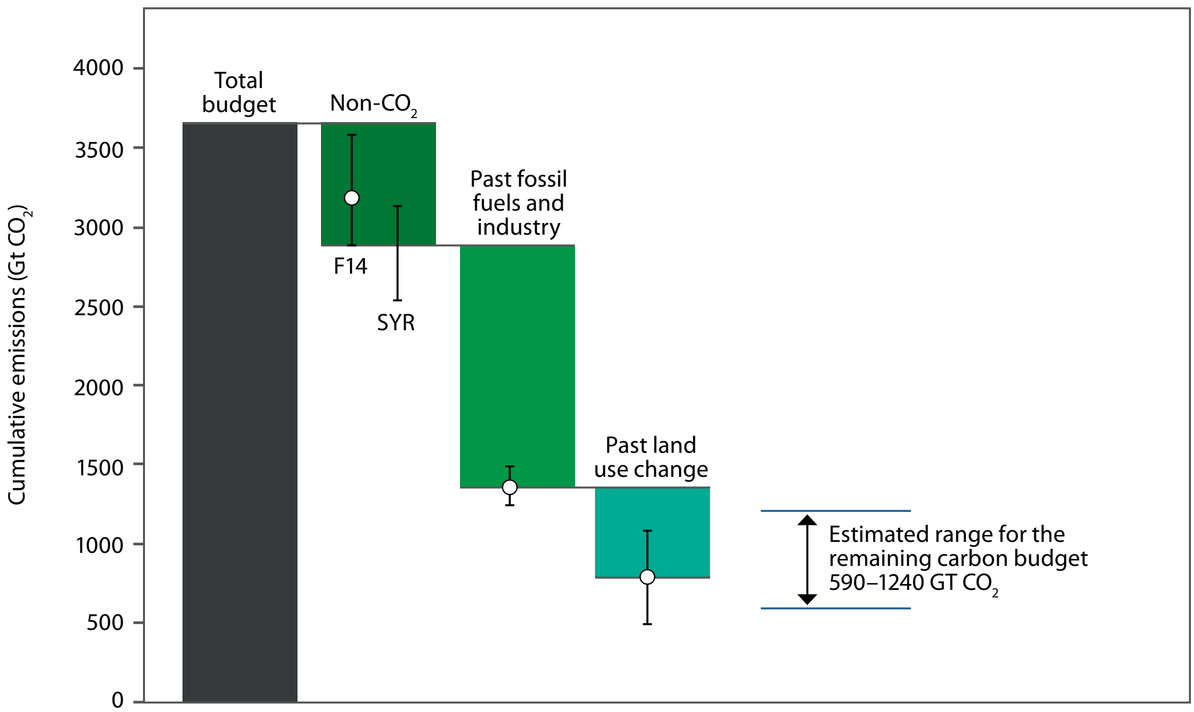

Figure 2. The total global carbon budget since pre-industrial times, and the remaining budget for CO_2 emissions after year 2015. Based on Global Carbon Budget 2016 (*www.globalcarbonproject.org*) and Rogelj *et al*. 2016.[9]

9. Rogelj, J., Schaeffer, M., Friedlingstein, P., Gillett, N.P., van Vuuren, D.P., Riahi, K., Allen, M., Knutti, R. 2016. Differences between carbon budget estimates unravelled. *Nature Climate Change* 6, 245–252.

Energy and materials

The energy sector is of particular importance in relation to the required transition to a low-carbon society. Fossil fuels continue to dominate the global energy mix and still provide more than 80 percent of primary energy worldwide. This ratio is almost the same as it was in the 1970's, despite the rapid growth in renewable energy technologies that has occurred in recent decades. In some parts of the world, policies have been introduced that have as their overriding goal the gradual phasing-out of fossil fuels. The EU 20/20/20 policy framework from year 2008 is one example of this. Nevertheless, investments in infrastructures and systems that rely on fossil fuels continue to predominate on the global level.

The use of materials and the associated industrial sectors are major sources of GHG emissions. The steel and cement industries combined accounted for around 8 percent of global energy use and almost 15 percent of global anthropogenic CO_2 emissions in 2012.[10] According to a recent study conducted by the International Resource Panel, almost half of the urban infrastructure that will be needed in year 2050 has not yet been built.[11] If the projected increase in infrastructure will be based on currently available GHG-intensive materials and technologies, a significant part of the carbon budget associated with achieving the 2°C target will be consumed by the production of materials alone. Thus, low-carbon processes for producing basic materials, such as cement and steel, will be needed. Furthermore, there will have to be increased resource efficiency (moving from linear to circular material flows) and substitution of materials.

The forest sector represents a significant opportunity for substitution of fossil fuels and GHG-intensive materials. In applications in which material substitution is difficult, biomass can be used to reduce the GHG intensities of the materials. For example, biomass that cannot be used to produce higher-value products, such as sawnwood, can be used in place of fossil fuels to provide the thermal energy needed for cement production.

10. IEA. 2015. Energy Technology Perspectives 2015 – Mobilizing Innovation to Accelerate Climate Action. International Energy Agency, Paris, France.

11. IRP. 2018. The Weight of Cities: Resource Requirements of Future Urbanization. Swilling, M., Hajer, M., Baynes, T., Bergesen, J., Labbé, F., Musango, J.K., Ramaswami, A., Robinson, B., Salat, S., Suh, S., Currie, P., Fang, A., Hanson, A. Kruit, K., Reiner, M., Smit, S., Tabory, S. A Report by the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya.

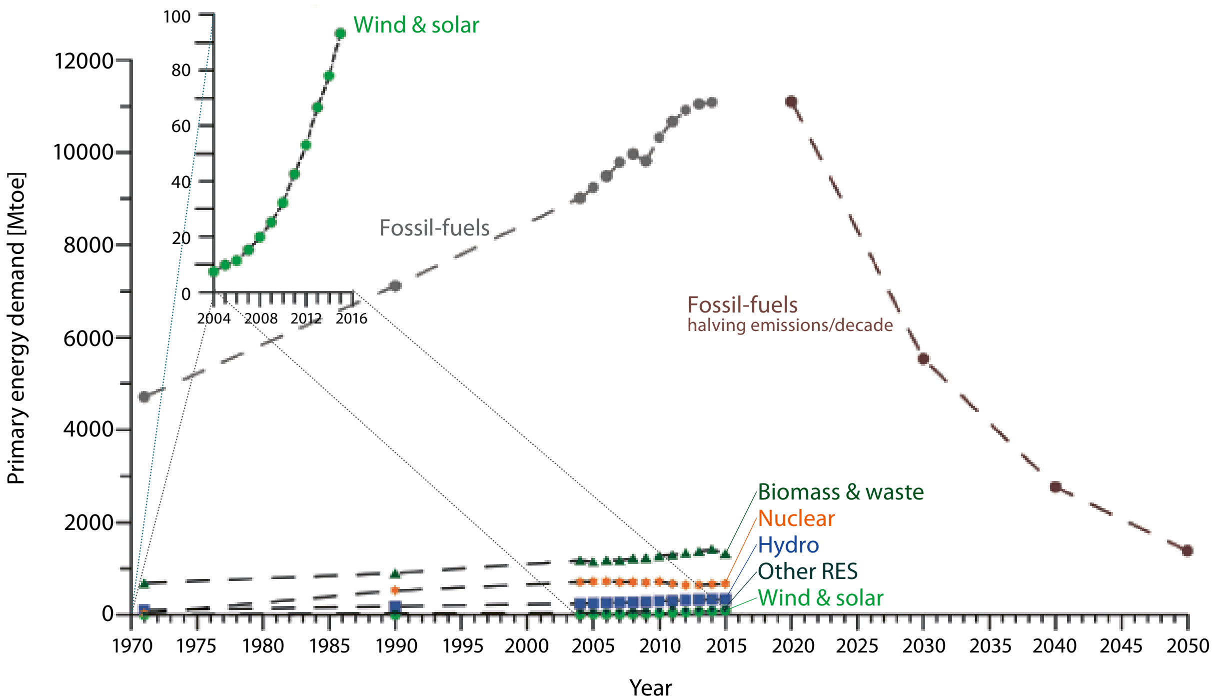

Figure 3. The development of primary energy consumption from fossil fuels, wind and solar, other renewables, hydro, and nuclear, from 1972 to 2015.

The filled symbols are approximations of the reductions in fossil-fuel consumption required if the gross anthropogenic CO_2 emissions are to be halved each decade in line with "the Carbon Law" proposed by Rockström *et al.* (2017).[12] The filled symbols assume that the ratio of coal to oil to gas usage is maintained at current levels while halving the emissions from fossil fuel use every decade, while not considering any offsetting of emissions through CCS.

Since the figure shows primary energy data, it conceals conversion losses (e.g. from combustible sources to electricity or well-to-wheel in road transportation systems) to final energy use supplied by oil, coal and gas (and biomass). In contrast, wind and solar power require higher capacities to produce the same amount of energy as thermal generation, due to the much lower number of full-load hours of wind and solar power. Thus, the actual deployment of zero-GHG-emission energy sources (in particular, wind and solar) required to replace fossil fuels while matching supply to demand, cannot be deduced directly from the figure. However, it will ultimately depend on the development of final energy demand and how the integration of wind and solar power is managed. Source: Johnsson *et al.* (2018).[13]

12. Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., Schellnhuber, H.J. "A roadmap for rapid decarbonization - Emissions inevitably approach zero with a 'carbon law'", *Science*, 24 March 2017, Vol 355, ISSUE 6331, pp 1269–1271.

13. Johnsson, F., Kjärstad, J., Rootzén J., The threat to climate change mitigation posed by the abundance of fossil fuels, Climate Policy, 2018, doi: 10.1080/14693062.2018.1483885.

European Union forests and biomass usage

The EU has reached a preliminary agreement (pending final adoption) that by year 2030 renewables will make up 32 percent of the overall energy mix in the EU. In terms of energy efficiency, the preliminary agreement proposes a non-binding target for year 2030 of 32.5 percent less energy than the level of use assumed for a business-as-usual scenario. Among renewable energy sources, bioenergy is currently the largest source, both within Europe and globally (Fig. 4). Most of the EU Member States have increased (in absolute terms) the use of forest biomass for energy, so as to reach their year 2020 renewable energy targets. Currently, about 96 percent of wood fuel use in the EU is based on domestic raw materials. Wood fuel exports from the EU are roughly equal to its wood fuel imports (about 4 percent).[14]

In industrialized countries, forest management addresses multiple purposes, including the production of paper, pulp and saw logs, bioenergy, and the provision of an array of ecosystem services (e.g. water flow regulation and purification, soil stabilization, air quality improvement, biodiversity conservation). Current bioenergy feedstocks consist mainly of by-products from sawnwood and pulp and paper production, as well as small-diameter trees and residues from silvicultural activities (e.g. thinning, fire prevention, salvage logging) and final felling. A large fraction of this biomass is used to supply energy within the forest industry. For example, sawmill residues are used for drying sawnwood, and pulp mills use black liquor, which is a byproduct of the pulping process, as an energy source. Energy co-products (electricity, heat and fuels) produced in the forest industry are also used elsewhere in society.

The EU accounts for approximately 5 percent of the world's forests and, contrary to what is happening in many other parts of the world, afforestation is increasing in the EU. Forests currently cover about 43 percent of the EU-28 land area, which is slightly higher than the percentage of land covered by agriculture. In seven EU Member States, forests cover more than half of the land area. Forest ownership is fragmented and varies from small family holdings to larger state- or privately-owned estates. Forest management practices vary significantly.

The harvested volumes in the forest sector currently correspond to about 73 percent of the net annual increment in European (EU-28) forests[15], which means that the carbon stock is growing over time. The total GHG mitigation effect of current forest management within the EU, manifested as annual increments to the forest sink, material substitution, and energy substitution, corresponds to about 13 percent of total current EU emissions.[16] There are signs of carbon sink saturation in European forests[17], and there are large uncertainties concerning the impacts of climate and other environmental changes on forest growth rates, decomposition rates, and natural disturbance regimes (fires, droughts, storms, insect infestations) – all of which will influence the strength of the future forest carbon sink and potentially, forest harvest volumes.

The variability of conditions requires that policy measures and actions are tailored to regional

14. Year 2017. Data available at: *http://www.fao.org/faostat/en/#data/FO*.

15. Losses due to natural disturbances are considered. Source: FOREST EUROPE, 2015: State of Europe's Forests 2015., Ministerial Conference on the Protection of Forests in Europe FOREST EUROPE Liaison Unit Madrid.

16. Nabuurs, G.J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M., Ollikainen, M. 2017. By 2050 the mitigation effects of EU forests could Nearly double through climate smart forestry. *Forests* 8(484); doi: 10.3390/f8120484.

17. Nabuurs, G.-J., Lindner, M., Verkerk, P. J., Gunia, K., Depa, P., Michalak, R. & Grassi, G. 2013. First signs of carbon sink saturation in European forest biomass. *Nature Climate Change* 3, 792–796.

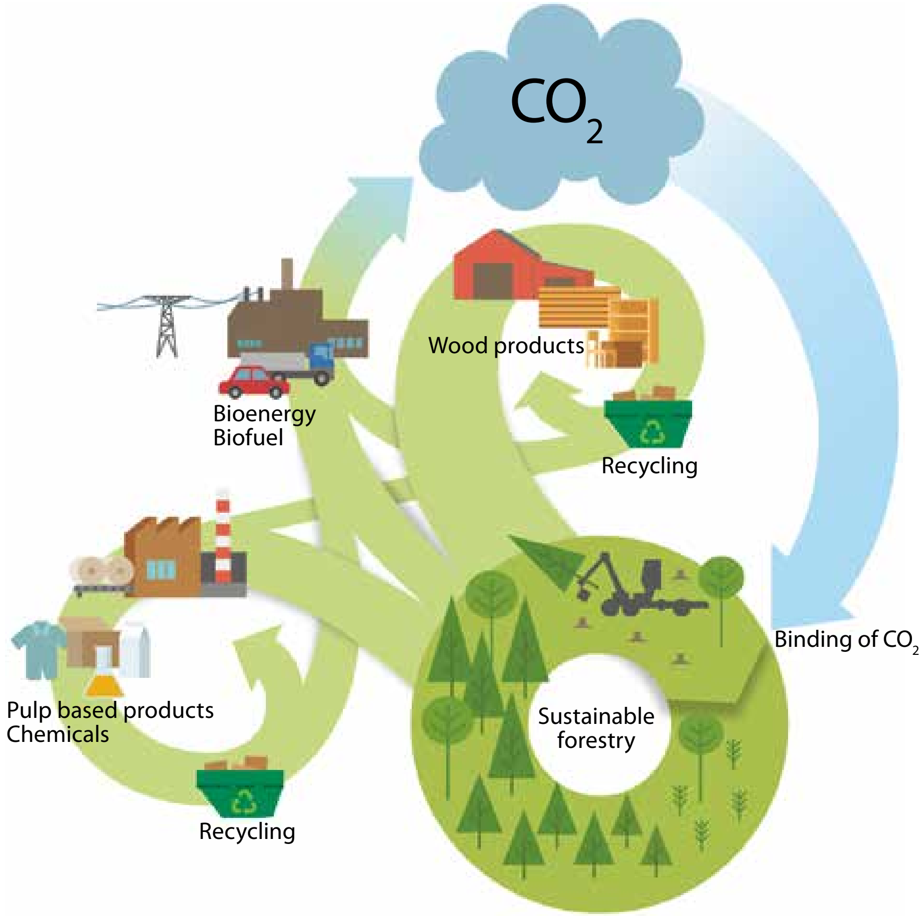

Figure 4. When forest biomass is used to produce pulp, paper and other forest products, bioenergy is produced simultaneously. Biomass from forestry operations and byproducts of wood processing are used to generate electricity, heat, and fuels. This bioenergy is used to meet the internal process energy needs of the forest industry, and it is also used outside the forest industry.
Picture source: Sveaskog.

circumstances, to enable the development of optimal practices in forest management for climate change mitigation. These measures should consider the diversity of forest types and management systems across Europe, ensure biodiversity safeguards, and aim to balance all forest functions. As an example of how European policymakers, governments, and actors in the forest sector could meet the challenges, Nabuurs *et al* (2017)[18] have shown that the EU forest sector could almost double the current GHG mitigation effect while also addressing other objectives.[19] While these quantifications are uncertain, they show that the future role of forests in climate mitigation critically depends on the chosen policies and forest management strategies. In this regard, the study carried out by Nabuurs *et al.* calls for intensification of efforts to improve understanding of the conditions for mitigation and adaptation to climate changes, as well as other environmental changes. As discussed below, climate forcers other than GHGs need to be considered, as these can have equally robust effects on the climate.

18. Nabuurs, G.J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M., Ollikainen, M. 2017. By 2050 the mitigation effects of EU forests could nearly double through climate smart forestry. *Forests* 8(484); doi: 10.3390/f8120484.
19. Climate Smart Forestry (CSF) outlined in Nabuurs *et al.* (2017) aims at supporting objectives to: 1) reduce GHG emissions and/or remove atmospheric CO_2; 2) adapt and build forest resilience to climate change; and 3) increase in a sustainable manner forest productivity and incomes for private and public forest owners, as well as associated industries.

The roles of forests and biomass in the Swedish climate strategy

Almost 70 percent of the Swedish land mass is covered by forests. Forestry and wood production are crucial components of the Swedish climate strategy. Biomass may be used to replace energy and materials that are associated with high-level GHG emissions, while at the same time atmospheric CO_2 is sequestered in growing forests and in forest products. In this respect, the most prominent areas are wood use in construction, combined heat and power production and district heating, green chemistry, viscose to replace polyester, new packaging materials, and biofuels.

The Swedish emissions reduction targets[20] are particularly ambitious for the transport sector, in that they are set to achieve a 70 percent reduction in CO_2 emissions by year 2030, as compared with year 2010. Electrification will assist this process, as will the expansion of public transport systems and climate-smart city planning. However, according to all forecasts, a large proportion of the vehicle fleet will still be powered by combustion engines in the period leading up to 2030. Therefore, a large part of the emissions reductions in the short and medium terms is planned to be derived from synthetic fuels, i.e., blending fossil fuels with biofuels. Such biofuels will to a large degree be produced from forest residue materials and byproducts of wood processing. Moreover, electrification is not predicted to be a solution for long-distance aviation or marine shipping. Furthermore, unless electric road systems will be implemented on a large-scale, synthetic fuels are expected to be required also for long-distance trucking fleets.

In relation to the Swedish climate targets, there are different views concerning the optimal balance to be achieved between carbon storage in the forests on the one hand and biomass harvesting to enable the substitution of fossil fuels and other GHG-intensive products on the other hand.

One view is that increased harvesting intensity, to meet the higher demand for forest products, will lead to substantial reductions in forest carbon stocks and carbon sink strength, thereby outweighing the GHG savings accrued from product substitution. There are also concerns about biodiversity impacts and a further constriction of the number of tree species being used, which may increase vulnerability to climate change. A particular concern is the likelihood that here will be an increasing number of clear-cut areas that emit CO_2 during the first 10–15 years after harvest. According to this view, a shift to using more forest products will not contribute to the aim "... to reach emission peaking as soon as possible" (Article 4 of the Paris Agreement). The favored strategy is to prioritize carbon sequestration and storage in forests over wood production for product substitution.

The alternative view is that forest management should aim for a consistently high wood yield, since the use of forest biomass for product substitution is an effective way to reduce GHG emissions. In addition, it is necessary for achieving a societal transition away from current infrastructures and technologies that rely on fossil fuels and other GHG-intensive products. According to this view, a strategy that prioritizes carbon sequestration and storage in forests has serious limitations. The capacity for carbon sequestration in forests declines as they become older. There is also the risk that the sequestered carbon will be inadvertently emitted to the atmosphere once again as a result of storms, insect infestations, and fires. This is further discussed below.

20. The climate targets are part of the Swedish Political Climate framework: see the official document from the Swedish Parliament at: *www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/klimatlag-2017720_sfs-2017-720.*

Forest–climate interactions

As described above, the interaction of forests with the climate system is complex. Climate change affects forests in different ways, and forests and the forest sector in turn influence the climate in different ways. *In this section, we attempt to crystallize the outcomes of the discussions that took place at the conference with respect to the main questions and topics presented in the Introduction section.*

1. Is there a difference between biogenic carbon emissions and fossil carbon emissions? Can biogenic carbon balances be omitted from climate impact assessments of forest products and systems?

The IPCC draws a distinction between two domains in the global carbon cycle. The *fast domain* consists of carbon in the atmosphere, oceans, and surface ocean sediments and on land in vegetation, soils, and freshwaters. There are large fluxes of carbon between these reservoirs (or pools), which have relatively short turnover times: vegetation and soil carbon sources have turnover times of 1–100 and 10–500 years, respectively. The *slow domain* consists of the carbon found in rocks and sediments. For these, turnover times are 10,000 years or longer (Fig. 5).

Biogenic carbon is found in the fast domain where it is stored in animals, plants, and organic matter in soils (the biosphere) and in biobased products, such as wood buildings, paper, food, and biofuels. Carbon is continuously circulated between the biogenic carbon pools and the atmosphere. It is removed from the atmosphere through photosynthesis and emitted to the atmosphere through respiration, decay, and combustion. Carbon is also transferred between the different biogenic carbon pools. For example, the carbon in vegetation is transferred to soils through litterfall. When a tree is harvested and used to produce sawnwood for the building industry, carbon is transferred from the forest into the building.

Fossil carbon emissions correspond to a linear flow of carbon from geological stores (the slow domain) to the atmosphere (the fast domain). This is fundamentally different from biogenic carbon emissions. *Fossil carbon emissions adds more carbon to the fast domain, while biogenic carbon emissions circulate carbon within the fast domain.*

Yet, as will be explained below, biogenic carbon should be considered in assessments of forest based mitigation options. They will otherwise not fully reflect how such mitigation options will affect atmospheric GHG concentrations.

Assessments of forest products and systems that omit biogenic carbon and that only consider supply chain emissions (e.g. GHG emissions associated with nitrogen fertilizer use and diesel use in farm machines and trucks) can provide the information needed to identify emissions hotspots in the supply chain or for implementing a policy decision (e.g. verifying that a certain biofuel option meets requirements concerning supply chain emissions). However, they cannot be used to estimate how the use of forest products and systems will affect atmospheric GHG concentrations.

The ways in which forests are managed influence significantly the carbon cycling in forests and, thereby, the amount of carbon that is stored in trees and soils. Carbon is also stored in forest products that differ with respect to lifetimes. The end-of-life treatments also differ, e.g. the discarded products may be recycled into new products, left to degrade in a landfill or used for energy in place of fossil fuels. Consequently, the carbon in products is kept out of the atmosphere over time periods that range from months and years (biofuels, paper, textiles) to decades/centuries (construction wood, furniture). In the future, carbon may be excluded from the atmosphere for millennia, if BECCS is employed.

Thus, *to capture fully their influences on atmospheric GHG concentrations, assessments of forest products and systems need to consider biogenic carbon balances in addition to supply chain emissions*. The notion that biogenic carbon need not be considered (the "carbon neutrality" assumption) may have some of its origin in the UNFCCC reporting. Here, biogenic carbon emissions associated with bioenergy are not included when energy sector emissions are reported. But

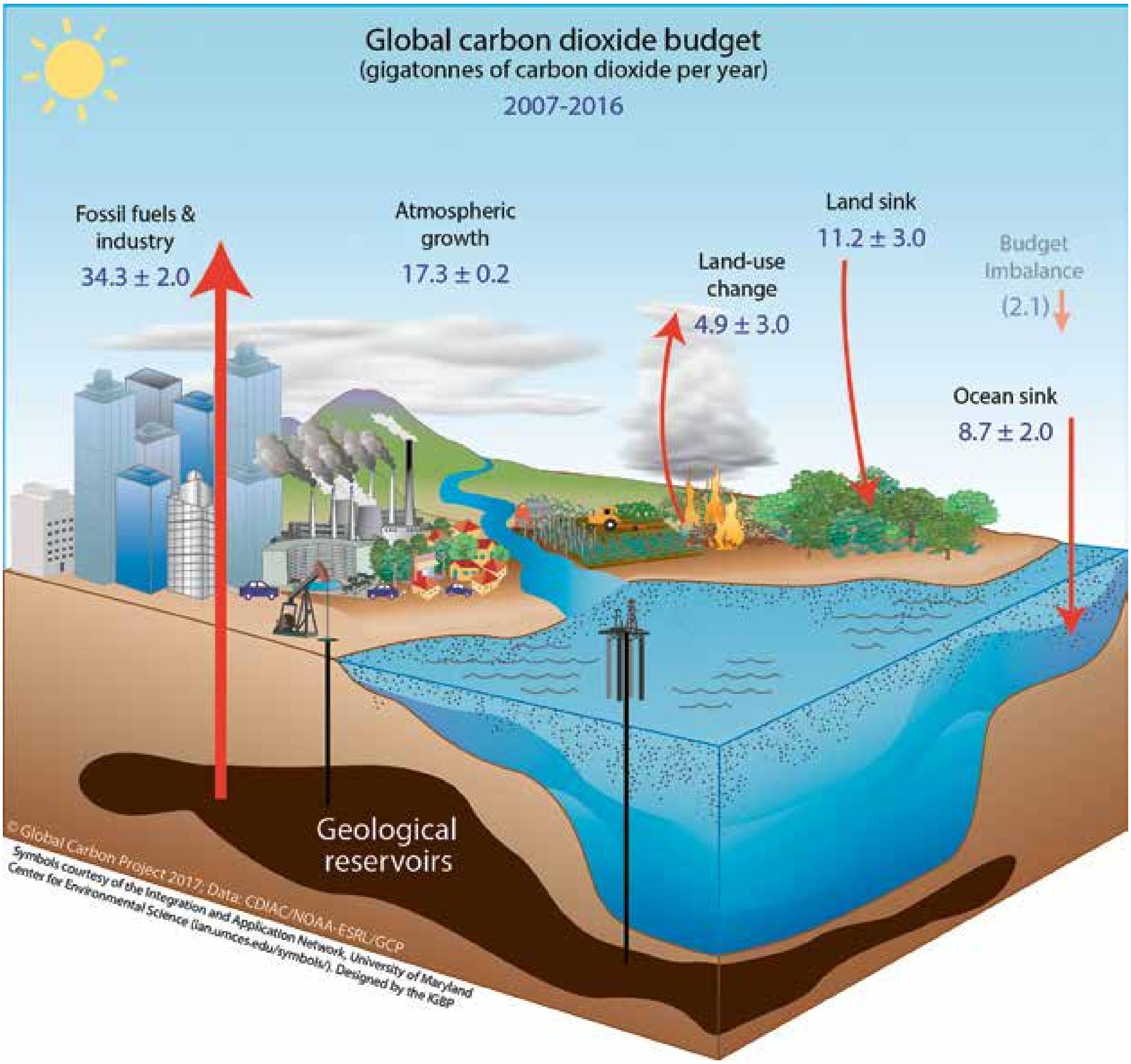

Figure 5. Perturbation of the global carbon cycle by anthropogenic activities, averaged globally for the decade 2007–2016 ($GtCO_2$/yr). The IPCC distinguishes between two domains in the global carbon cycle.
The *fast domain* consists of carbon in the atmosphere, the ocean, and surface ocean sediments and on land in vegetation, soils, and freshwaters. This domain undergoes large exchange fluxes and relatively "rapid" reservoir turnovers.
The *slow domain* consists of the carbon stored in rocks and sediments, which exchange carbon with the fast domain through volcanic emissions of CO_2, chemical weathering, erosion, and sediment formation on the sea floor. In these cases, turnover times are 10,000 years or longer.
Natural exchange fluxes between the slow and the fast domain of the carbon cycle are relatively small (<0.3 PgC per yr) and can be assumed to be essentially constant in time (volcanism, sedimentation) over the last few centuries, although erosion and river fluxes may have been modified by human-induced changes in land use. Biobased systems operate within the fast domain whereas fossil fuel use transfers carbon from the slow domain to the fast domain. Currently, this transfer of carbon to the fast domain is more than 35-fold larger than the natural exchange of carbon between the slow domain and the fast domain.
Picture source: Global Carbon Project [CC BY 4.0].

this is not because biogenic carbon emissions do not matter. The reason is that biogenic carbon emissions are included in the LULUCF reporting, so including them in the energy sector reporting would lead to double-counting.

Assessments of the GHG mitigation effects of forest management and biomass use, and the timing of these effects, need to be made from a systems perspective. It needs to be considered how GHG emissions change when forest products are used in place of fossil fuels and materials, such as concrete, steel, and plastics. Furthermore, assessments must consider how forest management, and the production and use of forest products, affect the strength of the forest carbon sink and the amount of carbon that is stored in forests and in forest products. Assessments should be made at the landscape level, to take full account of all the types of forest management operations that occur across the landscape. It is essential to include realistic representations of the age-dependence of forest growth rates so that it is considered that carbon accumulation rates diminish as forests age.[21]

2. What roles will biomass play in the energy system in the short, medium, and long terms?

It should be clear from Figure 3 that there is an urgent need to accelerate the transformation of the global energy system. There is a need for a broad range of energy conservation and efficiency measures, as well as renewable energy technologies to reduce the use of fossil fuels. Furthermore, investments in systems and technologies that rely on coal, oil, and natural gas need to be discouraged. All scenarios that meet the goals of the Paris Agreement include energy systems with large amounts of renewable energy.

Increased use of bioenergy and biobased products are part of the necessary mix and have the potential to make substantial contributions in lowering GHG emissions, by replacing fossil fuels and GHG-intensive materials. Biomass use for heat and power generation can be integrated into existing infrastructures in the energy and industrial sectors and will thereby achieve GHG savings in the near term, contributing to the phasing-out of fossil fueled heat and power generation. Wind and solar power (VRE; variable electricity generation) and electrification commonly play major roles in low-carbon scenarios. The use of various types of demand-side management, storage systems (storage for several days, as well as over shorter time-scales), and reservoir hydropower can complement thermal balancing power providing power stability and quality and maximizing the value of VRE.[22] In an energy system with large amounts of VRE, the value of dispatchable power based on biomass is likely to be high, provided that it meets the requirements of low net GHG emissions. The roles of the different options for integrating VRE will depend on regional conditions, such as wind and solar conditions, the availability of transmission capacity between regions, and the availability of biomass and reservoir hydropower.

Electrification of transport helps to improve energy efficiency and reduce local air pollution. However, it will take time to transform the current transport systems, and carbon-based transportation fuels will remain important in the coming decades. Biofuels can, together with electrification and improvements in vehicle energy efficiency, facilitate rapid and deep reductions in fossil fuel use in the transport sector. Therefore, it is important to develop and implement high-efficiency biofuel technologies in parallel with making greater investments in electrification as well as other energy supply options, such as wind and solar power.

In general, carbon-based fuels with low or zero net emissions to the atmosphere will attain an increasing value in a world that develops in line with the Paris Agreement, as schematically illustrated in Figure 6. In the short-to-medium term, biofuels are likely to be used extensively for road transportation.

21. Smyth, C., *et al*. 2014. Quantifying the biophysical climate change mitigation potential of Canada's forest sector. *Biogeosciences* 11, 3515–3529; Xu, Z., *et al*. 2017. Climate change mitigation strategies in the forest sector: biophysical impacts and economic implications in British Columbia, Canada. *Mitigation and Adaptation Strategies for Global Change* 23, 257–290.

22. Göransson, L., Johnsson, F. 2018. A comparison of variation management strategies for wind power integration in different electricity system contexts, *Wind Energy* 2018, 1–18. doi: 10.1002/we.2198.

In the longer-term, biofuels may primarily be used in applications in which the substitution of carbon-based fuels is difficult, such as aviation and long-distance ship transportation. However, innovation may help reduce dependency on carbon-based fuels also in such applications. In the second half of this century and thereafter, biomass may be increasingly used in BECCS applications to establish net-negative GHG emissions. BECCS applications will compete with other uses of biogenic carbon. High prices for biomass may lead to modifications to processes (e.g. electrification) in pulp and paper plants and in other industries that currently represent large point sources of biogenic carbon emissions (and thus, strong opportunities for BECCS).

It is obviously crucial that the possibility to achieve negative emissions in the future should not be used as an argument for postponing near-term

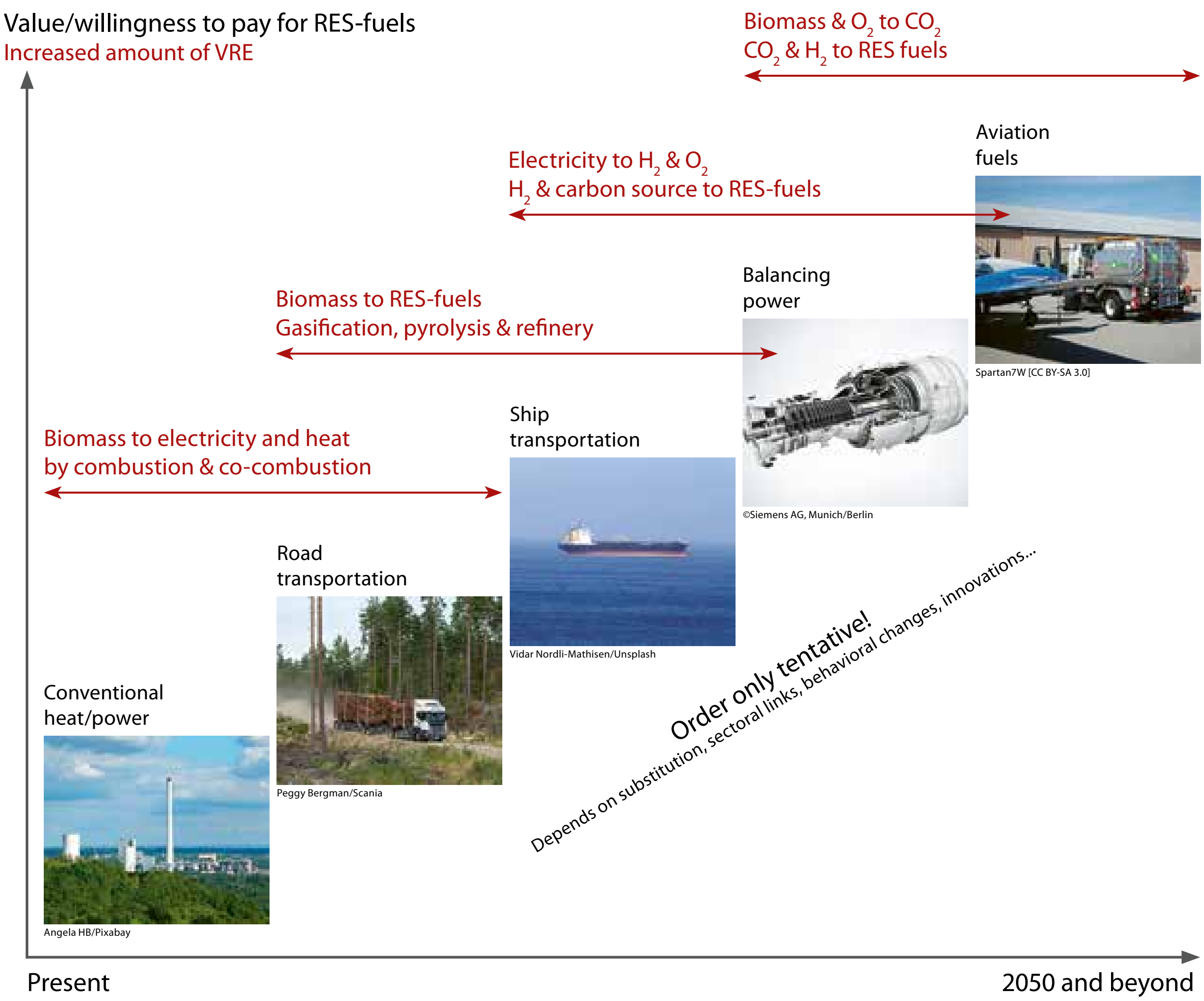

Figure 6. Schematic of the future uses of carbon-based (RES) fuels that do not directly originate from fossil oil, gas or coal, over the decades until GHG emissions have to be zero (and beyond, towards negative emissions). With the increased requirement to lower fossil-fuel emissions, there is an increase in the value of carbon-based fuels that have no net emissions of carbon to the atmosphere. This will cause biomass to be sourced to the sectors in which there is the strongest willingness to pay for biomass and in which substitution to other fuel sources (e.g. electricity) is difficult. In the long term, an alternative to biomass as a source of carbon-based fuels may be hydrogen from renewable electricity, combined with CO_2 from (biogenic) flue gases, the oceans or the atmosphere.

actions. Although BECCS and direct air-capture can contribute to negative emissions, they are both associated with large uncertainties with respect to costs and implementation potential[23, 24], as well as requiring the emergence of policy instruments incentivizing negative emissions technologies.[25]

3. How can forest materials substitute for GHG-intensive materials and reduce their GHG footprints?

Basic materials, such as steel, cement, aluminium, and plastics, account for a large proportion of global carbon emissions. There are three principal ways of reducing the climate impacts of these materials:

1. increasing the efficiency of resource use, including changing production processes (e.g., use of biomass instead of fossil fuels for process heat) and transitioning from linear to circular material flows;
2. changing lifestyles and consumption patterns; and
3. material substitution.

Innovations in both technologies and policies are essential for the necessary developments to take place. Efforts to boost innovation and to enhance resource use efficiency with regard to basic materials are currently being made. As an example of initial steps towards the needed deep cuts in emissions, the recently published roadmap for the cement industry, which is the second-largest industrial emitter of CO_2 with about 7 percent of global emissions, aims at reducing direct CO_2 emissions from the cement industry by 24 percent below current levels by year 2050.[26] While this is a step in the right direction, it is far from sufficient. A recently initiated roadmap activity for the iron and steel industry similarly aims at reducing emissions through innovative technologies, increased material and energy efficiencies, and switching to alternative fuels and processes.[27] As an example, hydrogen may in the in the longer term be used for reduction of iron ore in steel making.

Undoubtedly, change is slow and technology disruptions will not happen overnight. Even if there is a breakthrough for carbon-free production technologies, it is likely that society will for many decades be dependent upon basic materials such as steel and cement, for which the associated carbon emissions will remain high. Reducing atmospheric carbon emissions to levels compatible with the Paris Agreement temperature targets will, therefore, require a mix of solutions. This mix will include material substitution, the employment of CCS, and measures to reduce material flows in society.

Efforts are being made to move economies from more or less linear to circular material flows. Such a development would preserve value and reduce resource use and carbon emissions significantly. A circular economy, which is characterized by extended lifetime of products, design for reuse and recycling, and changing business models in favor of services rather than selling more stuff, is being advocated for in many regions of the world.

Biobased materials fit well with circular business models in which different ways of reusing, recycling, and cascading biomass can be developed and promoted. Biomass can be a near-term substitution option for several applications, such as replacing cement with wood in construction, using carbon fibers as a substitute for steel, and using biobased plastics, chemicals, clothing, and packaging.

It should be noted, however, that certain constraints apply to material substitution. For instance, more wood can be used in building construction, but

23. Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., ... Yamagata, Y. 2014. Betting on negative emissions, *Nature Climate Change* Vol 4, 2014, pp 850–853.
24. Larkin, A., Kuriakose, J., Sharmina, M., Anderson, K. 2017. What if negative emission technologies fail at scale? Implications of the Paris Agreement for big emitting nations, *Climate Policy* 2017, doi: 10.1080/14693062.2017.1346498.
25. Honegger, M., Reiner, D. The political economy of negative emissions technologies: consequences for international policy design, *Climate Policy*, Vol. 18, No. 3, 306–321, doi: 10.1080/14693062.2017.1413322.
26. IEA & CSI. 2018. Technology Roadmap – Low-Carbon Transition in the Cement Industry. International Energy Agency and the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD).
27. *https://www.iea.org/workshops/kick-off-workshop-for-the-iea-global-iron--steel-technology-roadmap-.html*.

some other applications, such as bridges, tunnels, and roads are more challenging. Furthermore, a precondition for substitution to take root is that carbon accounting methodologies will be improved, so as to substantiate more accurately the benefits of different types of substitution (avoided GHG emissions) and the storage of biogenic carbon in the biobased products.

4. What are the trade-offs between biomass production, carbon sequestration, and storage of carbon in forests and forest products? How do these trade-offs pertain to different climate change mitigation objectives?

The IPCC AR4 concluded that "… *in the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit*".[28] There is an apparent trade-off between the objectives to store carbon in the forest and the harvesting of wood for the production of forest products.[29] From the climate perspective, a reduction in carbon stocks is equivalent to carbon emissions, which compromise the GHG savings associated with forest product use. However, the two objectives are not mutually exclusive, and forest management decisions reflect the balancing of these and several other objectives.

The effects that forest management strategies exert on atmospheric GHG concentrations depend on:

1. how much GHG emissions are avoided when forest products substitute other products; and
2. how much carbon is stored in the forest and in forest products over time.

In this regard, long-lived forest products have a significant advantage in that they can be used to displace other products while keeping the biogenic carbon out of the atmosphere for a longer time than short-lived forest products, such as biofuels and paper. Many long-lived forest products also displace products that are associated with relatively large GHG emissions, such as cement and steel. Re-use, recycling, waste incineration with energy recovery, and BECCS can improve the mitigation value even further.

Forest management operations influence in different ways the strength of the forest carbon sink and the amount of carbon that is stored in forests over time. The outcomes of specific management decisions depend on the characteristics of the forest ecosystem, which are shaped by biophysical factors, such as soil and climate conditions, historic and present management schemes, and adverse events, including storms, fires, and outbreaks of insect infestation.

The forest carbon stock at the regional or national level may increase concomitant with increases in harvesting. The EU is one example of this, where the forest carbon sink and forest harvesting have increased simultaneously since the 1960s. One reason for this is the application of improved and more extensive forest management practices, following a historic period of deforestation. Other factors may also have an influence, not least climate and environmental changes (e.g. changes in temperature and CO_2 concentration, which both influence forest growth rate). However, the forest carbon stock may also decrease (or the carbon stock may increase at a slower rate) when forest management is changed to produce more forest products. For example, forest carbon storage may decrease if the forests are managed with shorter rotations or if larger volumes of logging residues are extracted.

28. Nabuurs, G.J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W.A., Matsumoto, M., Oyhantcabal, W., Ravindranath, N.H., Sanz Sanchez, M.J., Zhang, X. 2007. Forestry. *In* Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

29. Kurz *et al.* 2016. Climate change mitigation through forest sector activities: principles, potential and priorities. *Unasylva* 67, 3–9; Gustavsson, L., *et al.* 2017. Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels. *Renewable and Sustainable Energy Reviews* 67: 612–624.

As an alternative to increasing wood production, landowners may choose to harvest less biomass and store more carbon in their forests. Such a strategy can provide larger net GHG savings for a period of time.[30] Therefore, this may be considered preferable to a strategy that prioritizes wood production for forest products. This is especially the case if the main objective is to reduce the net GHG emissions to the greatest extent possible in the near term due to concerns over ocean acidification, risks relative to climate tipping points, and a desire to slow the rate of warming in the short term due to concerns about ecosystem adaptation to climate change.

A strategy that prioritizes carbon storage may steer development towards an end-point where forests store more carbon but have a lower capacity to produce biomass for various uses. The alternative is a strategy that aims to maintain net forest growth at a high level, allowing sustained harvesting. Furthermore, the contribution by wood harvesting to the necessary transformation of major sectors – through material substitution and bioenergy replacing fossil fuels – will no doubt be significantly lower. If forest disturbances, e.g. storms and fires, result in loss of some of the carbon that was sequestered, it may be even more difficult to fulfil longer-term climate objectives, such as those in the Paris Agreement. In many ecosystem types, the cumulative disturbance risk increases with forest age.

Figure 7 illustrates how the net carbon emissions to the atmosphere can change when forest management strategies are changed.[31]

In one scenario (Set-aside), the area of forest land that is left unharvested is doubled. Less forest products are produced than in the Business-as-usual scenario (BAU) but the carbon sequestration rate is higher in the set aside forest during a period of time. In another scenario (Production), silvicultural measures are introduced to increase forest growth and produce more forest products, which means a larger degree of substitution of GHG-intensive materials and fossil fuels.

As can be seen, the Set-aside scenario has lower cumulative emissions than the BAU scenario during most of the time period considered. This is because the lower emissions savings from product substitution in the Set-aside scenario (compared to BAU) is more than outweighed by larger carbon sequestration in the forest that is left unharvested. When the grey curve crosses the blue curve after about 85 years, the total amount of CO_2 that has been emitted to the atmosphere in the Set-aside scenario is the same as in the BAU scenario. Beyond this point in time cumulative CO_2 emissions to the atmosphere is higher in the Set-aside scenario than in the BAU scenario. In contrast to the Set-aside scenario, the Production scenario has lower annual net emissions than the BAU scenario throughout the considered time period. This is due to higher levels of forest growth and continuing biomass harvesting for material and energy substitutions.

The cumulative emission profiles in Figure 7 reflect a situation where the emissions savings associated with the use of specific forest products do not change much over time. It is sometimes argued that the emissions savings associated with bioenergy use can be expected to decrease over time if energy systems gradually become less dominated by the usage of fossil fuels. However, as explained earlier in this report, biomass will in such a scenario likely be used in applications where the substitution of carbon-based fuels is difficult (e.g. balancing power and aviation). Thus, fossil fuels will continue to be the alternative to biomass in a future situation in which renewable sources, such as wind and solar PV, play major roles. If innovation will make it possible to economically produce carbon-based fuels using direct air capture of CO_2, or to gradually phase-out carbon-based energy applications altogether (and if BECCS applications will not become established at

30. Some studies have indicated that the relative advantage of a carbon storage strategy endures over several decades. Other studies have found that forest management and wood harvesting to produce a mix of forest products provide the highest GHG savings, also in the short term.

31. The biomass that is harvested in the scenarios is used for building construction (large stemwood), pulp and paper production (small-diameter stemwood), and in combined heat and power or motor fuel production (small-diameter stemwood, logging residues, residues from wood processing, building construction and demolition). Thus, the GHG effects of the forest management strategies result from carbon storage in forests and forest products and from GHG savings associated with product substitution.

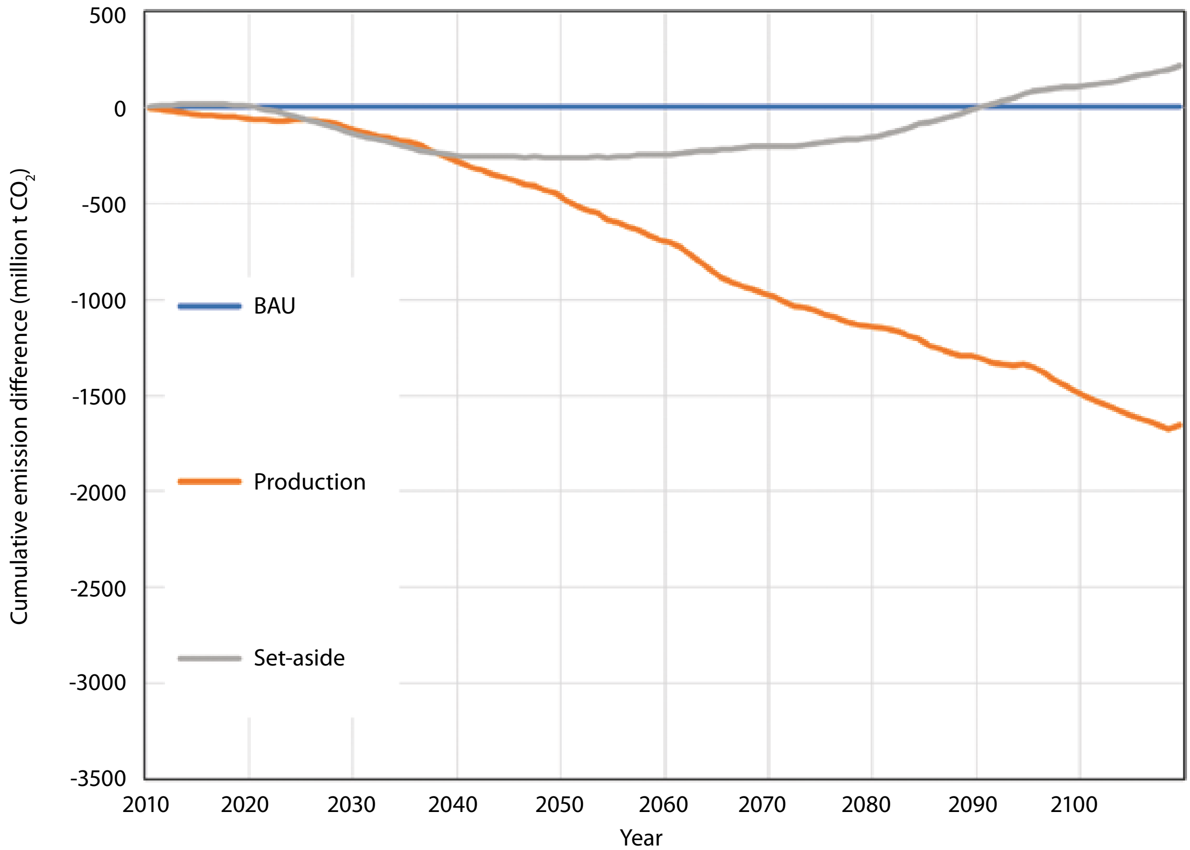

Figure 7. Differences in cumulative CO_2 emissions (Mt CO_2) resulting from different management strategies for Swedish forestry over a period of 100 years.[32] A Business-as-usual scenario (BAU), here set to 0, is compared with a Production scenario in which a number of silvicultural measures to increase forest growth is introduced, and a Set-aside scenario in which the area of set-aside land is doubled as compared to the BAU scenario. In all three scenarios, annual harvest equals annual growth, and forest residues corresponding to 8 TWh is harvested for the generation of heat and power each year. Although not shown in this diagram, an increased use of felling residues for bioenergy results in larger net GHG savings for all three scenarios, but with higher potential reduction for the Production scenario.

significant scale), then the biomass demand for energy will start to decline at some point in time.

The outcome outlined in Figure 7 is representative of the Swedish situation. The figure is primarily intended to illustrate how different forest management strategies can yield different outcomes. It should not be generalized for other countries. The outcome critically depends on the characteristics of the forest (e.g. age structure and species composition), which forest management practices are applied, and the GHG savings associated with the specific forest product mix. All of these factors can differ significantly between countries.

Finally, as already noted, forest management decisions reflect multiple objectives and measures to promote growth may be considered undesirable due to other considerations than climate change mitigation. In the Production scenario, Scots pine was

32. Gustavsson, L., *et al.* 2017. Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels. *Renewable and Sustainable Energy Reviews* 67: 612–624.

replaced by the faster growing lodgepole pine (*Pinus Contorta*) in 50 percent of the cases. This was done to illustrate the effects of a shift to fast growing species rather than proposing to introduce lodgepole pine at a larger scale. Any shift in species needs to consider knowledge gaps and/or higher risks than the commonly used species concerning aspects such as invasiveness, insect infestations, pathogens, and biodiversity.[33] A suitable mix of forest management measures, that may vary over time and with locations, may be used to achieve the forest productivity in the Production scenario while fulfilling other objectives.

5. What are the differences between rotation forest management and selection forest management in relation to carbon balances and biomass production?

In most countries in the boreal zone that have significant forest resources and an associated industry, the forest is shaped by *rotation-forestry systems* with even-aged forest stands. A balanced stand age distribution within the forest estate or at the national level is often the target. When a stand is harvested, the carbon balance switches abruptly from carbon sequestration to instant biomass carbon removal from the stand into forest products with varying lifespans. This is followed by net carbon emissions during the regeneration phase (mainly due to the decomposition of logging residues and soil respiration), and then a rapid net carbon gain in young stands. The net carbon gain remains high after canopy closure in more mature stands (20–100 years of age) and eventually declines as the forests become older.

At the forest estate level (i.e., a large area with a mosaic of stands of different ages, with carbon losses in some stands and carbon gains in other stands), the forest carbon stock is more stable and fluctuates around a trend line that can be increasing or decreasing or roughly stable. The harvesting of trees and managing stem densities and species composition help to maintain net forest growth (i.e., a carbon sink), allowing sustained harvesting. Forest growth rates can be enhanced through silviculture, such as species selection, planting, fertilization, and other management options

As an alternative to rotation forest management, *selection forest management* involves uneven-aged, structurally more complex forest stands and diversely structured and continuously maintained forest cover. Harvesting occurs at shorter intervals, with only 20–30 percent of the stand volume being removed from the stand during a harvest event. The carbon dynamics include net biomass carbon removal out of the forest during harvests, and a relatively stable net carbon gain in the uneven-aged stands. As is the case for rotation-forestry systems, the forest carbon stock is more variable at the stand level than at the forest estate level.

Rotation forestry systems have the advantage that they can include the harvesting of residues from silviculture operations and final felling, which can be used for energy production.[34] On the one hand, the rotation forestry system also offers opportunities to enhance forest growth (and consequently, carbon sequestration) through silviculture measures. On the other hand, selection forestry has the advantage that the ground vegetation and sub-canopy vegetation are continuously present and ready to utilize light and nutrient resources that become available each time a lower number of trees are harvested. As site preparation is generally not needed, the associated soil carbon losses are avoided.

Selection forestry is currently not widely practiced in boreal countries, although it is slightly more commonly used in Central and Southern Europe and western North America. It has been proposed as an alternative for the future where ecologically appropriate. Conversion from rotation forestry to selection forestry is in principle possible in any stand. This can be of benefit if an undergrowth reserve is already present, which will shorten the conversion period. However, it is clear that the conversion itself takes a long time.

33. Widenfalk, O. 2015. Contortatall i Sverige – En kunskapssammanställning och riskbedömning (*Pinus contorta* in Sweden – A knowledge compilation and risk assessment, in Swedish). Report Swedish FSC.

34. Recommendations must be followed concerning residue extraction and nutrient management (ash recycling and nitrogen fertilization), so as to prevent negative impacts, especially concerning biodiversity, soil nutrient balances, and acidification.

There are different views as to what conclusions can be drawn based on our current understanding of the growth patterns and carbon balances operating under the two management systems as well as during conversion from rotation forestry to selection forestry.

One view is that the conversion period is characterized by lower growth and lower yield of wood[35], and that a shift from rotation forestry to selection forestry will likely result in a lower carbon sequestration rate at the level of a single stand, at least during a transition period. According to this view, it is not possible to establish whether differences occur in the average standing volume over time, although there is some confidence that long-term growth in selection forestry is 10–20 percent lower than in rotation forestry.[36]

Another view is based on studies showing contrasting results[37] and stating that there is no conclusive evidence regarding differences in growth or in standing volumes over time between rotation and selection forestry systems. According to this view, it is not possible to establish whether the two management systems differ in terms of carbon uptake over time. The carbon balance is not only determined by the growth of the dominating trees, but as well by photosynthesis in the sub-canopies and ground vegetation and respiratory losses. The structural differences between the two management systems make comparisons of carbon balances difficult. Furthermore, carbon balances on the larger landscape level will not only depend on whether rotation forestry or selection forestry is used. It also depends on the balance between forest harvesting and growth, as well as the forest product portfolio.

Finally, it is generally agreed that a shift from rotation forestry to selection forestry may be motivated by other factors, e.g. the wish to create more favorable conditions for recreation, biodiversity, and ecosystem services.

6. How do different forest management strategies interact with other climate forcers than GHGs, e.g. reflection of solar radiation from Earth's surface? Should non-GHG forcers be considered when climate change mitigation strategies are developed for the forestry sector?

A full assessment of the role of forests in the climate system requires assessment of the impacts of radiative forcers other than by GHGs, namely surface energy exchange and aerosol loading through emissions of biogenic volatile organic compounds (BVOCs) (see Fig. 8). The emitted BVOCs can form aerosols which can affect cloud formation.[38]

BVOCs can contribute to both cooling and warming of the atmosphere, depending on where and when the emissions occur, types of BVOCs emitted, and the fates of the molecules in the atmosphere.[39, 40] The process underlying BVOC emis-

35. Eerikäinen, K., Valkonen, S. & Saksa, T. 2014. Ingrowth, survival and height growth of small trees in uneven-aged *Picea abies* stands in southern Finland. *Forest Ecosystems* 1(5). 10 p; Lähde, E., Laiho, O. & Norokorpi, Y. 2001. Structure transformation and volume increment in Norway spruce-dominated forests following contrasting silvicultural treatments. *For. Ecol. Manage.* 151: 133–138; Lundqvist, L. 2017. Tamm Review: Selection system reduces long-term volume growth in Fennoscandic uneven-aged Norway spruce forests. *Forest Ecology and Management* 391: 362–375.

36. A recent review showed that the selection system reduces long-term volume growth in Fennoscandic uneven-aged Norway spruce forests by 10%–20%. Lundqvist, L. 2017. Tamm Review: Selection system reduces long-term volume growth in Fennoscandic uneven-aged Norway spruce forests. *Forest Ecology and Management* 391: 362–375.

37. Results obtained from field experiments and measurements conducted in uneven-aged Finnish forests from the 1930s until the present day, showing that uneven-aged stands often grow faster than even-aged stands with the same post-cutting stand density. Laiho, O., Lähde, E., Pukkala, T. 2011. Uneven- vs. even-aged management in Finnish boreal forests. *Forestry* Vol. 84, No. 5, 2011. doi: 10.1093/forestry/cpr032.

38. Tunved, P., Hansson, H.-C., *et al*. 2006. High natural aerosol loading over boreal forests. *Science* 312: 261–263.

39. Unger, N. 2014. Human land-use-driven reduction of forest volatiles cools global climate. *Nature Climate Change*, doi: 10.1038/nclimate2347.

40. Aamas, B., *et al*. 2017. Regional temperature change potentials for short-lived climate forcers based on radiative forcing from multiple models. *Atmos. Chem. Phys.* 17, 10795–10809.

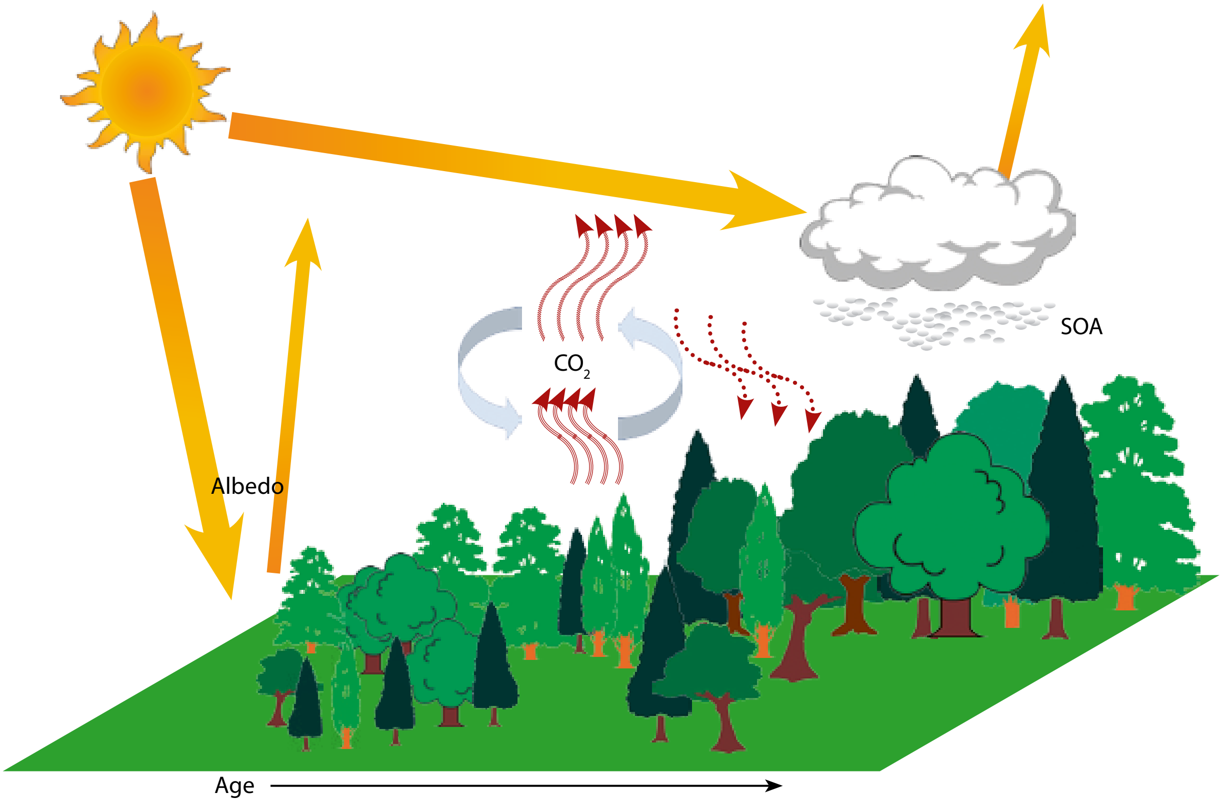

Figure 8. The main processes that influence radiative forcing: surface albedo, CO_2, and secondary organic aerosols, SOA. The yellow arrows indicate direct radiation from the sun, and the red arrows represent infrared radiation.

sions is complex and influenced by both abiotic and biotic factors. The types of BVOCs that are produced vary between tree species, as well as within specific genera.[41] The complex atmospheric processes that occur within the lowest part of the atmosphere contribute further to the uncertainty.[42]

The surface energy exchange of forests also affects climate forcing, both through the radiation balance and through the fluxes of sensible and latent heat. Deciduous tree species generally have significantly higher reflectivity (albedo) than conifers[43], which means less warming. The species difference is also important during the snow season, as different forest types, including different management stages, have very different albedo values depending on the degree of exposure of the (snow-covered) forest floor to the atmosphere (Anderson *et al*., 2010). Rotation-managed forests also show differences in albedo and energy fluxes during the clear-cut phase (higher reflectivity), as compared to the closed canopy phase.[44]

41. Van Meeningen, Y. 2017. Is genetic diversity more important for terpene emissions than latitudinal adaptation? Doctoral dissertation, Lund University, Dep Physical Geography and Ecosystem Science, ISSN 978-91-85793-82-2, 149 pp.

42. Spracklen, D.V., Bonn, B., *et al*. 2008. Boreal forests, aerosols and the impacts on clouds and climate. *Philos. T. Roy. Soc. A.* 366: 4613–4626.

43. Bright, R.M., Anton-Fernandez, C., *et al*. 2014. Climate change implications of shifting forest management strategy in a boreal forest ecosystem of Norway. *Glob. Change Biol.* 20: 607–621; Kuusinen, N., Lukes, P. *et al*. 2014. Measured and modelled albedos in Finnish boreal forest stands of different species, structure and understory. *Ecol. Mod.* 284: 10–18.

44. Bright, R.M., Anton-Fernandez, C., *et al*. 2014. Climate change implications of shifting forest management strategy in a boreal forest ecosystem of Norway. *Glob. Change Biol.* 20: 607–621.

It is well-established that the above-mentioned processes can be equally important as GHGs. For example, a recent study[45] concluded that the effects of global cropland expansion between the 1850s and 2000s on BVOC emissions and atmospheric chemistry have imposed a cooling corresponding to a net global radiative impact of -0.11 ± 0.17 W m^{-2}, a magnitude comparable to that of the surface albedo and land carbon release effects.

Other recent studies[46, 47, 48] have reported mixed results and significant uncertainties. Concerning albedo effects, a study[49] of land use change and management in Europe since 1750 revealed a very significant warming effect of species conversion through forest management towards more conifers which have a lower albedo as compared to deciduous trees.

Nevertheless, due to the inherent uncertainties and complexity of modelling, few studies have to date included the effects of all the processes. In particular, assessments that include the effects of BVOC emissions and aerosols are still premature due to the large uncertainties related to the descriptions of these processes and the complex interactions with atmospheric chemistry and cloud-climate interactions.

Among the assessments carried out for Nordic countries, a study for Finland[50] that employed different future harvest scenarios found that the effects of albedo and BVOCs were substantial but opposite in terms of impact; in practice, they cancelled each other out. However, it was underlined that the uncertainties were too severe to draw definitive conclusions. A study for Norway[51] found that cooling aerosols and albedo offset 60–70 percent of the total warming associated with the use of forest biomass in wood-burning stoves and wood biomass-based district heating. Whether the net effect turns out to be warming or cooling depends on the substitution effect of using biomass for energy.

45. Unger, N. 2014. Human land-use-driven reduction of forest volatiles cools global climate. *Nature Climate Change*, doi: 10.1038/nclimate2347.

46. Scott, C.E., *et al*. 2017. Impact on short-lived climate forcers (SLCFs) from a realistic land-use change scenario via changes in biogenic emissions. *Faraday Discuss.* 2017, 200, 101.

47. Heald, C.L. and Geddes, J.A. 2016. The impact of historical land-use change from 1850 to 2000 on secondary particulate matter and ozone. *Atmos. Chem. Phys.* 2016, 16, 14997–15010.

48. Szogs, S., *et al*. 2017. Impact of LULCC on the emission of BVOCs during the 21st century. *Atmospheric Environment* 165: 73–87.

49. Naudts, K., Chen, Y., *et al*. 2016. Europe's forest management did not mitigate climate warming. *Science* 351: 597–599.50. *https://www.biogeosciences-discuss.net/bg-2017-141/bg-2017-141.pdf.*

51. Avesen, A., *et al*. 2018. Cooling aerosols and changes in albedo counteract warming from CO_2 and black carbon from forest bioenergy in Norway. *Scientific Reports*, doi: 10.1038/s41598-018-21559-8.

Future research and collaboration activities

While the KSLA conference and the related, current report do present several conclusions and areas of consensus upon which policymakers can build, it is clear that further research and collaborative activities are needed. Following the discussions during the conference, we have identified knowledge gaps and uncertainties, including future policy initiatives in the areas of climate, energy, biomass, and forestry. Even though this falls outside of the direct scope of this report, we take this opportunity to propose the following plan of action:

- Support national cross-sectoral analysis of the contribution of land use and biobased systems in reducing the radiative forcing in the atmosphere over varying time scales. Such an analysis should consider all the climate forcers and include the forestry, agriculture, energy, and other relevant sectors, such as the building industry.

- Establish a research program to further the knowledge concerning interactions between climate change, human activities and natural ecosystem processes, such as aging and disturbances – and how these interactions will affect non-GHG climate forcers as well as the capacity of forests and other ecosystems to sequester and store carbon over time. This program should address both rotation forestry and selection forestry, and also transitions from the former to the latter.

- Analyze and compare *the role of biomass in different sectors*. Many sectors (industry, transportation, electricity, heating, etc.) have expectations on biomass as a mitigation option. Total biomass demand may become larger than what can be made available while continuing to provide a range of other social, economic and ecological functions. The available biomass is likely to be supplied to the sectors/actors that have the highest willingness to pay. This will depend on the relative strength of incentives for change in different sectors and the availability of other than biobased options for substitution of GHG intensive fuels and materials..

- Clarify the differences in terms of climate impact of selective forestry and rotation forestry respectively – considering CO_2 and other GHGs, the effects of albedo, evapotranspiration, and BVOCs – as well as aspects related to biodiversity and resilience.

- Develop, evaluate and improve methods and tools relevant for monitoring, reporting and verification of carbon stocks and flows in forests and in forest products. In addition, investigate applicability at different (country, regional, global, company) levels and the possibilities for integration with current national forest inventory systems, so as to facilitate high-level efficiency of data collection.

- Establish stronger science and policy collaborations among boreal countries related to the impacts of climate change as well as mitigation and adaptation strategies. The boreal countries all face serious consequences of climate change and there is much to be gained from expanding collaborative research activities. The International Boreal Forest Research Association (IBFRA) can serve as a vehicle to advance a research agenda. Examples of areas in which these countries could benefit from cooperation include GHG flux measurements, carbon quantification based on remote sensing, and research into non-GHG climate forcers.

Abbreviations and acronyms

BECCS	Bioenergy with carbon capture and storage
BVOC	Biogenic volatile organic compounds
GHG	Greenhouse gases
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land-use change and forestry
SFM	Sustainable forest management
UNFCCC	United Nations Framework Convention on Climate Change
VRE	Variable renewable electricity

Program

Monday, 12 March

10:00 Welcome
Lisa Sennerby Forsse, President of the Academy, KSLA

SESSION 1: The carbon cycle and the role of forests in climate change mitigation

10:05 Introduction
Mattias Goldmann, moderator

10:10 Societal transitions towards climate neutrality: challenges and strategic choices
Anders Wijkman, Co-president Club of Rome, Chair Climate Kic

10:25 EU policy processes of relevance for the theme of the conference
Fredrick Federley and Jakop Dalunde, Members of the European Parliament

10:35 Introduction to the expert workshop: background, working procedures and expected outcome
Göran Berndes, Professor, Chalmers University of Technology, Sweden

11.00 Open discussions

11:30 Lunch & poster session

SESSION 2: Assessing the climate effects of forestry and biomass production – why the lack of consensus?

13:20 The carbon cycle and forest-climate interactions: principles and considerations
Werner Kurz, Dr. Senior Research Scientist, Canadian Forest Service, Canada

13:50 Assessing the climate effects of forestry and biomass production: the outcome depends on questions asked and how these are answered
Annette Cowie, Adjunct Professor, University of New England, Australia

14:20 Understanding the bioeconomy: principles, considerations, and insights.
Robert Abt, Professor, College of Natural Resources, NC State University, USA

14:50 Open discussions

15:20 Coffee/tea

SESSION 3: The climate effects of forestry and biomass production – carbon balances under different forest management regimes

15:50 Comparison of selection systems and rotation-forestry system: conditions for biomass extraction, carbon balances and climate effects
Johan Bergh, Professor, Linné University, Sweden

16:10 A principal choice – manage forests for wood production or leave the forest as a carbon sink: carbon balances and climate effects
Gert-Jan Nabuurs, Professor, Wageningen University, The Netherlands

16:30 Climate effects of forestry and substitution of carbon-intensive materials and fossil fuels – a country level study for Sweden
Leif Gustavsson, Professor, Linné University, Sweden

17:00 Comment and reflections on the presentations
Invited commentators

17:30 Open discussions

18:00 End day 1

Tuesday, 13 March

08:30	Registration of new participants
SESSION 3: Continued	
09:00	The climate impact of forestry extends beyond its carbon budget *Sebastiaan Luyssaert, Associate Professor, Vrije University, Amsterdam, The Netherlands*
09:30	Finnish case study – to increase or not to increase harvesting level. Do the biophysics matter? *Tuomo Kalliokoski, Postdoctoral researcher, University of Helsinki, Finland*
10:00	Synthesis and conclusions from sessions 2–3 *Mattias Goldmann, moderator*
10:30	Coffee/Tea
SESSION 4: Meeting the targets of the Paris Climate Agreement – the role of forests and biomass	
11:00	Bioenergy in the energy system – now and in the future *Filip Johnsson, Professor, Chalmers University of Technology, Sweden*
11:30	Together towards the bioeconomy – bioenergy done right *Åsa Forsum, Head of unit Sustainable bioenergy, The Swedish Energy Agency*
12:00	Comments and reflections on the presentations *Invited commentators*
12:30	Open discussions
13:00	Lunch
SESSION 5: Presentation and discussion of workshop outcome	
14:00	Input from policy, authorities, industry and research
15:00	Coffee/tea
15:30	Panel discussion with audience
16:30	Summary and conclusions
17:00	Closing of the conference

Participants

Robert Abt, Professor, NC State University, USA
Lovisa Ahlsén, Research Coordinator, PREEM AB
Cecilia Akselsson, Dr, Lund University
Ola Alterå, Chief Executive, Swedish Climate Policy Council
Kjell Andersson, Policy Director, Svebio
Peter Axegård, Bioeconomy Strategy, RISE
Daniel Badman, Head of Public Affairs, Stora Enso
Niclas Scott Bentsen, Associate Professor, University of Copenhagen
Johan Bergh, Professor, Linné University
Göran Berndes, Professor, Chalmers University of Technology
Björn Boström, LULUCF-expert, Environmental Protection Agency
Erik Brandsma, Director General, Swedish Energy Agency
Pål Börjesson, Professor, Lund University
Sandro Caruso, Dr, Formas
Annette Cowie, Adjunct Professor, University of New England, Australia
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Katarina Eckerberg, Professor in political science, Umeå University
Gustaf Egnell, Associate Professor, Swedish University of Agricultural Sciences
Lena Ek, Chairman of the Board, Södra
Isak Engqvist, Assistant, EU Parliament
Lars Ericson, Professor emeritus, Umeå University
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Per Erik Karlsson, Professor, Swedish Environment Research Institute/IVL
Åsa Kasimir, Ass Professor, University of Gothenburg
Carl Kempe, Chairman, Kempestiftelserna
Raziyeh Khodayari, Energiföretagen
Leif Klemedtsson, Professor, University of Gothenburg
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Pekka Leskinen, Professor, Head of Bioeconomy Programme, European Fores Institute
Maj-Lena Linderson, Dr, Director, ICOS Sweden Lund University
Anders Lindroth, Professor emeritus, Lund University
Mattias Lundblad, Researcher, Swedish University of Agricultural Sciences
Anna Lundborg, PhD, Swedish Energy Agency
Rickard Lundin, Professor, Royal Swedish Academy of Sciences
Tomas Lundmark, Professor, Swedish University of Agricultural Sciences
Sebastiaan Luyssaert, Associate Professor, Vrij University, Amsterdam
Anna Malmström, Program manager, Swedish Energy Agency
Robert Matthews, Science Group Leader, Forest Research, UK
Elin Mellqvist, Commitee Secretary, Royal Swedish Academy of Sciences
David Mjureke, Adviser, Ministry of the Environment and Energy
Christina Moberg, Professor/President, Royal Swedish Academy of Sciences
Emilie Molin, Desk Officer, Ministry of Enterprise and Innovation
Gert-Jan Nabuurs, Professor, European forest resources, Wageningen University, The Netherlands
Birgitta Naumburg, Secretary, Forestry Section, KSLA
Lena Niemi Hjulfors, PhD, Swedish Board of Agriculture
Hans Nilsagård, Senior advisor, Ministry of Enterprise and Innovation
Magnus Nilsson, Director, Magnus Nilsson Produktion
Mats Nilsson, Professor, Swedish University of Agricultural Sciences
Sten Nilsson, Professor, Forest Sector Insights
Thomas Nilsson, Programme Director, Mistra
Annika Nordin, Professor, Swedish University of Agricultural Sciences
Jessica Nordin, Climate and Land use Strategist, Sveaskog
Matthias Peichl, Associate Professor, Swedish University of Agricultural Sciences
Karin Perhans, Senior Research Officer, PhD, Swedish Research Council Formas
Birgitta Resvik, Vice President, Fortum
Henning Rodhe, Professor emeritus, Stockholm University, Department of Meteorology
Lars Ronnås, Ambassador for climate change, Ministry of Environment and Energy
Ingrid Rydberg, PhD Agriculture, Committee for agriculture's climate adaptation, KSLA
Lisa Sennerby Forsse, President, KSLA
Risto Sievänen, Dr, Natural Resources Institute Finland
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Jenny Spets, Director Communication, Swedish Forest Industries Federation
Johan Stendahl, Ass Professor, Swedish University of Agricultural Sciences
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Timo Vesala, Academy professor, University of Helsinki
Anders Wijkman, Chairman, Climate Kic
Göran Örlander, Forest Policy Expert, Professor of Silviculture, Södra

Issues of the Royal Swedish Academy of Agriculture and Forestry Academy Journal (KSLAT).

(Titles marked with * are only published on the KSLA website www.ksla.se, where also earlier editions are to be found.)

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Nr 6 Forests and the climate. Manage for maximum wood production or leave the forest as a carbon sink?

The Paris Agreement sets ambitious targets for climate mitigation, which require transformation of the production and consumption systems that generate greenhouse gas (GHG) emissions, mainly due to fossil fuel use. The interaction of forests with the climate system is complex. The scientific literature provides a variety of views on how different forests and forest management options can be adapted to climate change – and there are also divergences in view on how they affect the climate.

This report summarizes the discussions from the 2-day international conference *Forests and the climate: Manage for maximum wood production or leave the forest as a carbon sink?* in March 2018 at the Royal Swedish Academy of Agriculture and Forestry in Stockholm, Sweden. The aim was to facilitate dialogue among experts representing different views related to forest management and climate change mitigation, to help advance scientific understanding, and to identify knowledge gaps and priorities for future research and data collection.

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