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# Multi-functionality and sustainability in the European Union's forests

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# EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by the member academies and by contracts with interested bodies. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities include substantive studies of the scientific aspects of policy issues, reviews and advice about specific policy documents, workshops aimed at identifying current scientific thinking about major policy issues or at briefing policy-makers, and short, timely statements on topical subjects.

The EASAC Council has 29 individual members – highly experienced scientists nominated one each by the national science academies of EU Member States, by the Academia Europaea and by ALLEA. The national science academies of Norway and Switzerland are also represented. The Council is supported by a professional Secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale) and by a Brussels Office at the Royal Academies for Science and the Arts of Belgium. The Council agrees the initiation of projects, appoints members of working groups, reviews drafts and approves reports for publication.

To find out more about EASAC, visit the website – www.easac.eu – or contact the EASAC Secretariat at secretariat@easac.eu

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EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Jägerberg 1
D-06108 Halle (Saale)
Germany
tel: +49 (0)345 4723 9833
fax: +49 (0)345 4723 9839
email: secretariat@easac.eu
web: www.easac.eu

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# Contents

# Foreword

The European Academies' Science Advisory Council's (EASAC's) mission is to help policy-makers in European institutions gain access to the latest science and technology related to contemporary policy issues. Often this involves working at the frontiers of science and technology where new capabilities raise new regulatory issues, but equally sectors covered by long-established laws and regulations may need revision as a result of new knowledge or societal priorities. Forestry is one such sector with a history going back hundreds of years and regulatory structures ranging from local through national to European (and global) scales. However, recent shifts in society's demands and substantial improvements in our knowledge of forest ecosystems and the potential contribution of ecosystems services to society's needs have called into question the adequacy of historical regulatory structures. As a result, there are several forest-related policy issues currently under debate within the European Union (EU).

Forests offer important opportunities for wealth and job creation in rural areas, as well as crucially important habitats for many endangered species of fauna and flora and protection from natural hazards such as erosion, landslides, avalanches and flooding. They attract visitors and tourists wishing to enjoy a growing range of leisure activities, while also contributing to the mitigation of global warming. Forests can be managed and harvested in different ways to produce forest biomass, which can be made into a wide range of products including timber for construction and furniture, pulp for making paper, and a growing number of biochemical, bioplastics and fuels. Forests differ widely across the EU because of differences in climate and in forestry traditions and policies. In addition, forests are changing in many parts of the EU because of the effects of climate change, which include higher temperatures, lack of rainfall, wildfires, damaging storms, diseases and insect infestations.

Reflecting this current situation, EASAC welcomed an offer by the Finnish Academy of Science and Letters to lead a special project focusing on the sustainability and multi-functionality of Europe's forests. EASAC Council adopted this project in late 2014 and over half of EASAC's member academies nominated experts to review the relevant science. These experts covered a wide range of disciplines, and provided geographic coverage from the Mediterranean to the Arctic, and from Portugal in the west to Hungary in the east. This expert group provided a strong scientific foundation for EASAC to develop this report, which reviews recent scientific knowledge, analyses its relevance to policy and presents concise evidence and conclusions for use by EU policy-makers.

The evidence confirms that there are important conflicts between the competing demands being made of Europe's forests and the finite resources and services that they can offer. In the context of EU policy-making, it is important to recognise that several different international agreements and policy areas have an impact on EU forests, even though they may not be labelled as forestry policies: for example, the Paris Agreement on climate change, and the Convention on Biological Diversity. Moreover, when looking to the future it is clear that targets, such as those proposed in the recent EU package on 'Clean Energy for all Europeans', could have major impacts on the future of EU forests and need to be taken into account when making or updating national policies for sustainable forest management. Our analyses indicate that only by adopting a coherent and holistic approach will be it possible for EU policy-makers to maximise the value of the multiple functions of forests and to deliver the optimal social, environmental and economic benefits from this finite resource.

I express my thanks on behalf of EASAC to Professor Jaana Bäck from the University of Helsinki, who chaired the working group and played a key role in drafting this report together with the EASAC Environment and Energy Programme Directors. I also thank the experts from EASAC member academies who contributed directly to this report, and the officials from five Directorates-General of the European Commission who kindly provided information and evidence that informed the discussions leading to the policy advice contained in this report.

An important aim of publishing this report is to stimulate further discussions between policy-makers and stakeholders who are working in areas that could impact on the future of EU forests. EASAC and its member academies encourage such discussions in Brussels and in EU Member States, and will be pleased to contribute to such discussions.

Thierry Courvoisier
EASAC President

# Summary

Although forest management policies remain the responsibilities of Member States, EU policy already recognises the interplay of different aspects and policy objectives within the common theme of ‘forests’: in wealth creation and employment, natural resources and raw materials, nature conservation and biodiversity, mitigation of and adaptation to climate change, and in energy and agriculture. Consequently, some 10 Directorates-General in the European Commission are responsible for policies that concern forests. This creates a significant challenge to policy-makers to ensure a systematic approach, to avoid conflicts and to enhance sustainability and synergies between different policy domains. In particular, recent decisions in the Convention on Biological Diversity and the Paris Climate agreement require fast and firm actions related to the use and management of forests and their products. Such global objectives require that national, regional and global policies are consistent with each other.

These global objectives are set against a background of additional factors.

- Shifts in the demands and expectations from forests, and a broadening in the potential markets for woody biomass (including biorefining and bioenergy).
- Forests are increasingly influenced by stakeholders from many parts of society, with varying interests some of which compete with each other.
- Forestry resources are affected by several factors which have not yet been taken fully into account in national or international policies; for example, diseases, invasive species, climate change and land use changes. Knowledge and evidence concerning the non-market ecosystem services provided by forests is increasing, including that on climate change mitigation through carbon storage, conservation of biodiversity and protection against erosion.

With a significant increase in scientific knowledge over the past decade, EASAC undertook this study, led by the Finnish Academy of Science and Letters together with a wide and multidisciplinary expert group, to review current scientific knowledge and consider how the multiple functions of forests can be managed sustainably to deliver the optimal social, environmental and economic benefits from this finite resource. In particular, this report focuses on scientific knowledge related to the many factors contributing to forests’ interaction with climate change, and the ways in which different policies and management structures may interact with biodiversity.

The interaction of forests with climate change is complex. The function given the highest priority in the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) is to manage forests sustainably so as to enhance forest carbon stocks to help mitigate climate change. EU forests are already contributing to this through their annual increment of wood, which is currently equivalent to an uptake of about 100 million tonnes of carbon annually (approximately 10% of Europe’s fossil fuel emissions). However, science suggests that the processes underlying this may be transient and that the forest-based carbon sink has an upper limit, which may already have been reached in some areas. Nevertheless, potential may still exist for increasing the carbon sink of European forests through well-designed management. Here, while younger, faster-growing forests may have a higher **rate** of carbon uptake from the atmosphere, it is the older, longer-rotation forests and protected old-growth forests that exhibit the highest carbon **stocks**.

The overall impacts of forests on the atmospheric carbon budget depend heavily on the uses made of the harvested forest products (wood). Where the wood is captured in construction or other long-term uses, its carbon is kept out of the atmosphere for long periods and the demand for other carbon-intensive materials such as steel or concrete is reduced. In contrast, the use of wood in bioenergy releases its carbon to the atmosphere very swiftly. In assessing overall climate impacts therefore, the whole chain from forest ecosystem to wood products and energy substitution needs to be taken into account. In addition, forests influence climate by biophysical processes, such as cloud formation processes and albedo, which depend on tree species diversity, stand density, types of forest management and location. Depending on the combination of the above factors, the impacts of forests on global average temperatures can be positive or negative. This report examines aspects related to the net effect of forests on climate, including the net effects on climate of using forest biomass as a source of fuel and its comparison with fossil fuels.

This report also examines the need to recognise the importance of different ecosystem services provided by Europe’s forests. These include some services that are valued by the market (for example tourism and recreation), but many that are not assigned a market value. Some 65 million EU citizens harvest mushrooms, berries and other wild foods; forests provide habitats for diverse fauna and flora (including game for the EU’s 13 million hunters), protection from natural hazards such as erosion, landslides, avalanches, flooding,

and poor water and air quality. These services are underpinned by biodiversity, which increases resilience to the impacts of environmental change and forests' ability to provide such services.

This report points out that the principles of sustainable forest management (SFM) applied in the EU recognise the multi-functionality of forests and the need to maintain the ecological functions of forests and their ecosystem services, while fulfilling their economic and social functions. However, Europe's forest ecosystems are already under pressure due to existing impacts of climate change and forest management, and are expected to become more stressed in the future. In addition to climate change, human efforts to mitigate and adapt to climate change can both positively and negatively affect biodiversity and other ecosystem services. Our analyses thus shows tensions between some of the objectives of SFM—especially between demands for increased extraction of biomass from forests and the contributions made by the same biomass *in situ* to soil fertility, biodiversity and protective functions. Other synergies and trade-offs exist in the way in which forests' interaction with climate change mitigation is managed.

The report reaches several important conclusions.

- Biodiversity underpins the ecosystem services of forests, and a decline in biodiversity threatens the ability of both managed and natural ecosystems to adapt to changes in their environment. This links the sustainability of forest management to both conservation of biodiversity and climate impacts, as diverse ecosystems are often more efficient in providing climate change mitigation.

- The role of forests is particularly important for biodiversity, and action is required to protect the remaining critical habitats (old-growth forests), restore already degraded areas, as well as to include more biodiversity considerations in forest management. Tools to meet biodiversity conservation targets vary between eco-climatic regions, but improved coordination between national biodiversity protected areas is required.

- Public and private forest owners increasingly recognise the multiple use of forests and their ecosystem services. This is generating a need for a new, diversified forest management approach that potentially conflicts with policies that focus narrowly on raw materials provision.

- The climate impact of forest management is not just related to their effects on atmospheric carbon, since changes in albedo, other greenhouse gases and cloud formation can be significant. Forest management from a climate perspective should incorporate such biophysical effects. Increasing the carbon storage in existing forests is a cost-effective measure to decrease net carbon emissions, but EU policies are currently biased towards the use of forest biomass for energy with potential negative effects on the climate over the short to medium term. The economic principle that '*cleaner earns, polluter pays*' suggests that carbon storage should be subsidised and emissions from forest bioenergy should be fully accounted for and controlled through appropriate means.

- A critical factor in the use of forest biomass in energy provision is the 'payback time', during which atmospheric concentrations of carbon dioxide ($CO_2$) will be increased as a result of using biomass. EASAC concludes that the European Commission should consider the extent to which large-scale forest biomass energy use is compatible with UNFCCC targets (of limiting warming to 1.5 °C above pre-industrial levels), and whether a maximum allowable payback period should be set in its sustainability criteria.

- Since using wood in durable commodities and construction allows carbon to be stored over long periods, these uses should be stimulated. At the end of their life, the same wood can then be used for bioenergy (and/or biorefining) within the framework of a cascade approach.

- A critical feature in the current policy implementation of the EU carbon accounting procedure is how the future forest reference levels for the Member States are specified. These should be set on scientifically objective grounds and incentivise climate change mitigation.

- EASAC agrees with much of the European Commission's recent analysis on the underlying issues related to the role of forest biomass for energy and that the primary purpose of biomass energy is climate change mitigation. Compared with some other renewable energy sources, the impact of biomass energy on levels of carbon dioxide in the atmosphere is very poor, and renewable subsidies should reflect this.

- Other issues covered in the report include short rotation forestry, accounting procedures used in the land use, land-use change and forestry (LULUCF) sector, the possibility of payments for ecosystem services, and general SFM practices contributing to both biodiversity conservation and climate change mitigation.

Overall, the current scientific evidence on forests' role in climate change and on the current status of both biodiversity and forest vitality has significant implications for future forest policies and management.

Policies should better account for the multi-functionality of forests and should better optimise the balance between social, economic and ecological contributions. To find a better balance between the competing demands on Europe's forests may require different management approaches based on *local* scientific evidence. Forest management approaches in one region may not be directly transferable to other forest climatic zones: for example, the impacts of forest management strategies such as continuous cover silviculture and the enhancement of native tree species diversity and landscape heterogeneity may contribute to different extents to the maintenance of forest cover, the conservation of carbon stocks and biodiversity, and the improvement of the social and cultural values of forests.

## A final word

Debate on the European Commission's 2016 energy package (EC, 2016a) offers an opportunity to address the core issues raised about forests' sustainability and multi-functionality. These include better management of carbon stocks, enhancing forest biodiversity and ecosystem services, while ensuring forest biomass use delivers real reductions in greenhouse gas emissions over a period that is meaningful from a climate perspective. Through its own independent studies and through the EU Science Advisory Mechanism (SAM), EASAC looks forward to continuing to provide scientific input to support the Commission's policy development process.

# Background

The EU has a vision of sustainable forestry contributing to the economy of its Member States and to the environment—both regionally and globally. In the latter context, the role of forests in biodiversity conservation and climate change mitigation has become increasingly important through the United Nations Convention on Biological Diversity (CBD) and the UNFCCC.

Forests in the EU's 28 Member States stretch from the Atlantic in the west to the Black Sea in the east, and from the Mediterranean in the south to the Arctic in the north. Forest management has evolved at a national or sub-national level influenced by the quantity and nature of the forest resources available, forecasts on their future development, impacts of demand, and local economic and social factors. The evolving management of forest resources has been affected in recent years by substantial shifts in the demands and expectations from forests as a resource, while the forest resource itself is subject to new pressures which are not yet sufficiently taken into account in national or international policies. These pressures include diseases, invasive species, and the effects of climate change on forests through drought, increasing temperatures, storms and other forms of extreme weather.

Many forests continue to provide the traditional forest products of timber, pulp, paper, etc., but forested areas are also expected to provide important ecosystem services, including climate change mitigation, conservation of biodiversity, recreation and protection against avalanches and erosion. A key policy issue is how the existing and future forests in the EU, which are limited in size and have a fragmented ownership, should be managed to deliver in a sustainable way an optimal mix of social, environmental (including biodiversity conservation) and economic services. The management options selected may lead to many different outcomes depending on the initial state of the forest, and the end use of the harvested wood, so that complex trade-offs may emerge. For instance, some management actions may increase a forest's future potential for carbon capture and storage, while others may release previously bound carbon into the atmosphere.

Such interactions call for a multidisciplinary approach to the physical, chemical and biological, as well as social and economic, aspects of forestry; a key consideration in forest management is thus their multi-functionality. However, not all forests provide the same range of functions; nor may they all be available at the same time. There can thus be important trade-offs or win–win options when formulating forest management policies from the perspective of multi-functionality. Forest management may thus benefit from a more systems approach, where scientific understanding provides inputs to policy tools that guide the optimal use of forest resources.

In response to this perceived need, EASAC, with the support of the Finnish Academy of Science and Letters, decided to undertake this study to collate the underlying science related to the most important functions of EU forests and their management, and to provide advice and guidance from a scientific perspective on how to move towards an optimal mix of functions and services from the EU's forests.

This project has been guided by an expert group, nominated by the Academies of Science in 14 countries (see Annex 1)[1]. Following initial reviews to identify areas of significant recent science, the expert group decided to concentrate on two of the current EU policy priorities to which forests are increasingly being required to contribute, namely climate change impacts/mitigation and biodiversity conservation, and to examine their links to forest policies.

The report begins with a short overview of the current state and uses of Europe's forests, explains how forests are reacting to the changing climate, and then focuses (Chapter 3) on biodiversity conservation and the trade-off between biodiversity, traditional forest management and the rapidly growing bioenergy production. The ways in which forests interact with climate and can be both a sink for, and source of, greenhouse gases and other climate-forcing effects are discussed in Chapter 4. The report then addresses (Chapter 5) the potential for optimising forest management in different parts of the EU, taking into consideration the potential for trade-offs between various targets which have been set by the EU alone and in international treaties, and which depend on contributions from European forests. Finally, conclusions and recommendations are presented which address potential EU policies related to the sustainability and multi-functionality of European forests.

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[1] The project was led by the University of Helsinki on behalf of the Finnish Academy of Science and Letters, and three workshops were held to identify critical policy issues, view the latest science and refine the report.

# 1 Introduction to the EU's forests

## 1.1 Key characteristics of Europe's forests

Forests cover approximately 42% of the land area in the EU (161 million hectares (1 hectare = $10^4$ $m^2$); Forest Europe, 2015) which is about 5% of the world's forests. About 87% of European forest area is classified as semi-natural, 4% natural and 9% as plantations. While approximately 25% are protected under Natura 2000 legislation, overall only 2% can be considered strictly undisturbed. Most undisturbed forests are found in Northern and Central-East Europe (Food and Agriculture Organization of the United Nations (FAO), 2015).

Forest ecosystems in the EU are diverse, spanning several climatic and biogeographic zones[2] of which the boreal, Mediterranean and temperate (Atlantic and continental) zones constitute 87% of the land area. Each zone exhibits different species, growth rates and contrasting management traditions, which have evolved over hundreds of years. The climate, soil and hydrological factors determine the potential climax vegetation[3] and, combined with past and present human impacts, have resulted in the present-day variety of forest types. There are various existing schemes of forest classification; one showing the distribution of the main tree species is shown in Figure 1.1 (Brus *et al.* 2011).

More detailed information on various forest types[4] is given in Box 1. It can be seen that forest categories are distributed rather differently among the 28 EU Member States. Not only does the total forest area per country vary greatly but also the distributions of the various forest types are different. Box 1 highlights the connections between forest categories and the political units that administer them, and the inherent complexity of European forest management.

Box 1 also provides information on forest ownership, statistics related to its use and ecosystem services. This shows profound regional differences: for example, the importance of other wooded lands in the south, the vastness of the Northern forest, and the higher growth rates of Central European forests. Note also the different importance of ecosystem services such as erosion control in mountainous countries, and the prevalent low degree of naturalness in some countries. By volume, more than half the EU forest is coniferous and about 60% of EU forest area is privately owned. Current management practices vary widely according to forest type and the local approaches developed to suit the landscape and the type and rate of forest production. These practices range from felling and extraction of wood to harvesting forest products from standing trees (for example cork, acorns for livestock). Management regimes typically include, for example, clear-cut harvesting (including periodic thinning, and covering larger or smaller areas) in the Nordic countries, plantation forestry in some parts of southern and western Europe, continuous cover management,

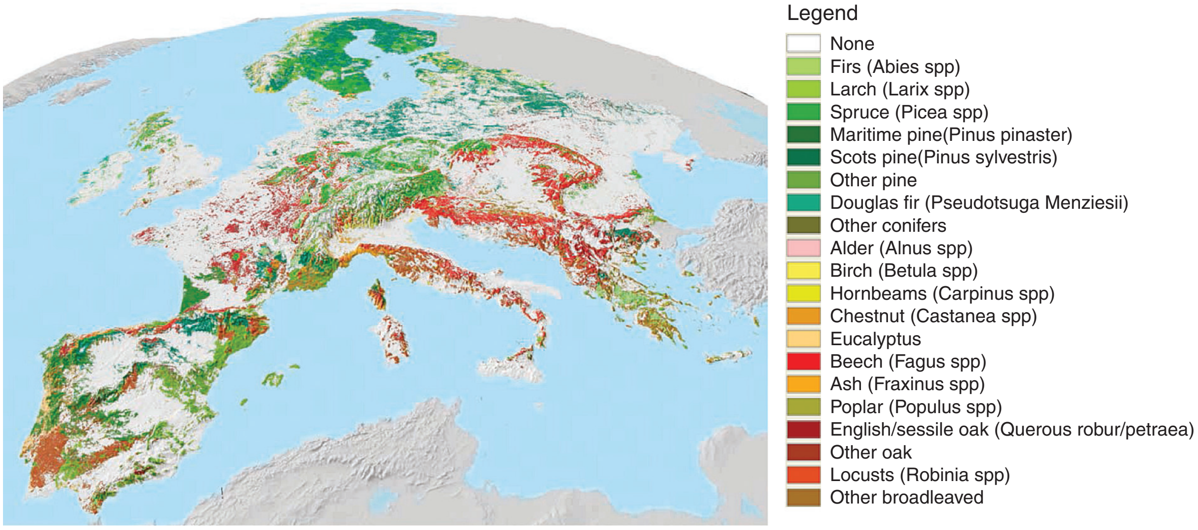

*Figure 1.1 Tree species map of EU forests across Europe (reproduced from Brus et al., 2011).*

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[2] The European Environment Agency assigns the EU's biogeographical zones to Atlantic (18.4%), Boreal (18.8%), Continental (29.3%), Alpine (8.6%), Pannonian (3.0%), Steppic (0.9%), Black Sea (0.3%), Mediterranean (20.6%) and Macaronesian (0.2%).

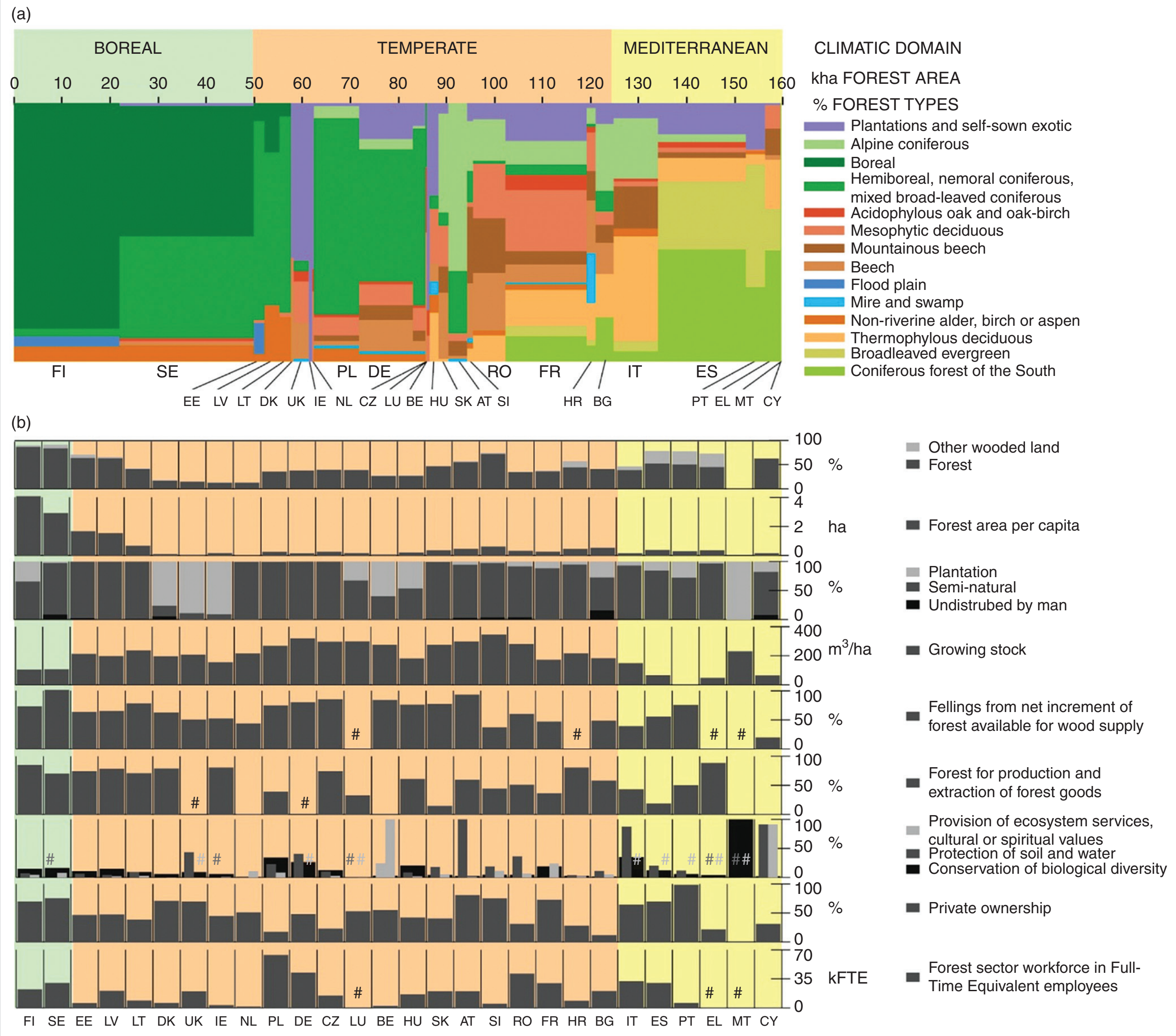
[3] Ecosystems are always dynamic but climax vegetation is understood to be one that, through the process of ecological succession in any given area over time, reaches conditions approaching an apparent steady state.

[4] Using a classification system adopted to assist the Ministerial Conference on the Protection of Forests in Europe in the assessment of sustainable forest management.

### Box 1 Characteristics of the forests the 28 EU Member States

The upper panel (a) in the figure below shows the total size of the forest area and how it is distributed through the major climatic zones (categories of the FAO). Several biogeographical regions span the area but are not shown here for simplicity. Within each climatic zone, proportions of 14 forest types (right) are depicted both for the total forest area and within countries, according to the European Environment Agency (EEA, 2006). (The width of the columns indicates the area in each country while the colours indicate the different forest types.)

The lower panel (b) shows per-country values (relative to the total forest area of that country) of some key indicators on forest characteristics (share of forest over total country area and the comparison with other wooded land, forest area per capita, and the degree of naturalness); production (growth and share of increment that is actually felled); forest use (share of forest designated for production and for protective functions); socio-economic context (private ownership and the forest sector workforce). Values are for 2015 (if not available, 2010); missing values are marked with a hash symbol (#). Data were gathered from FAO (2015) and Forest Europe (2015).



retention forestry (integration of biodiversity concerns in production forests) and forests without active management in several Central European locations (Gustafsson *et al.*, 2012; Nabuurs *et al.* 2015).

Especially in Sweden, Finland, Norway, Poland, Austria and the Baltic countries, forestry plays an important economic role. Forests in Central European countries have high stocks and higher annual increments compared with the European average. South-west European forestry includes a diverse range of practices, from Atlantic plantations of exotic species to dry Mediterranean forests of low productivity and low rates of management, but which at the same time provide many ecosystem services, agroforestry and protect against desertification. The Mediterranean forests are at the same time expanding their cover and being threatened by forest

**Box 2 Sustainable Forest Management**

Sustainability has been a concept in forestry for centuries in the context of ensuring that harvest should not exceed new growth to secure a regular long-term production of wood products. This has progressively expanded to accept that forest management should not just focus on timber as a commercial product, but that it should aim at a broader provision of human-valued products and services (Kuhlman and Farrington, 2010). Since the Brundtland Report of 1987, 'sustainability' has become associated with the United Nations definition which recognises that '*Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development*'. Following several Ministerial Conferences on the Protection of Forests in Europe, the term 'sustainable forest management' (SFM) was defined in 1993 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 fulfil, 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*' (Helsinki Resolution H1). In addition, Forest Europe has provided guidelines for pan-European criteria for SFM, which include indicators and monitoring (Lisbon Resolution L2). These criteria and indicators have been continuously revised, and six criteria were adopted by the 46 Member States to the 7th Forest Europe Ministerial Conference in 2015, shown in the Table below.

*Pan-European criteria for Sustainable Forest management*

| | |
|---|---|
| 1. Global carbon cycles | Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles |
| 2. Health and vitality | Maintenance of forest ecosystems' health and vitality |
| 3. Productive functions | Maintenance and encouragement of productive functions of forests (wood and non-wood) |
| 4. Biological diversity | Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems |
| 5. Protective functions | Maintenance, conservation and appropriate enhancement of protective functions in forest management (notably soil and water) |
| 6. Socio-economic functions | Maintenance of other socio-economic functions and conditions |

fires, exacerbated by increased temperatures and drought events associated with climate change and increased pressure from human activities. Non-wood products and services (for example edible products, grazing, tourism) are often important, although not always properly valued.

## 1.2 Sustainability and the use of forests, forest services and products

Northern EU countries are areas of traditionally intensive forest management with a dynamic forest sector and innovative technological developments in the timber industry. In contrast, Southern Europe exhibits a lower level of economic activity in forestry and the timber industry, and few systems for the remuneration of social and environmental services that may well be of greater importance than timber production. Nevertheless, forest management (for example for grazing and harvesting of firewood) and its impact on the structure of the forest can still be high.

Adaptive capacity in the forestry sector is relatively high in the boreal and temperate oceanic regions. In the temperate continental region of Eastern Europe, adaptive capacity in the forest sector is restricted by socio-economic constraints, such as a lack of investment in forest enterprises or the timber industry, an under-developed legal system to secure sustainability of forest management, and a lack of infrastructure to access the forest resource and adapt forest management to changing market conditions.

Currently, the forestry sector is undergoing large structural changes in many Member States, to accommodate changes in the demand for wood, paper and pulp, the emergence of the green economy/bioeconomy, as well as moves towards a circular economy (EASAC, 2015) and decision-making based on value cascading (Olsson *et al.*, 2016; Ciccarese *et al.*, 2014). The latter principle implies the priority use of wood material based on the higher added values that can be generated along the wood value chain, where the use of wood for energy (after recycling opportunities to produce other products have been exhausted) is typically the least valuable option[5].

A key underlying factor is an expectation that the use of forests should be 'sustainable', where the importance of managing forests and forest lands in a sustainable way has been recognised internationally by the United Nations and the EU at ministerial levels. Management guidelines and indicators for performance monitoring have been published by the EU, with the aim of maintaining the biodiversity, productivity, regeneration capacity and vitality of forests as well as their potential to fulfil relevant ecological, economic and social functions (see Box 2).

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[5] The use of the wood cascade is stressed in the Commission's Circular Economy package (COM (2014) 398), which states it will encourage the cascading principle for the sustainable use of biomass. The EU Forest Strategy document (COM (2013 659) also determines that wood be used in the order of the following priority: wood-based products, extension of service life, re-use, recycling, bioenergy and disposal.

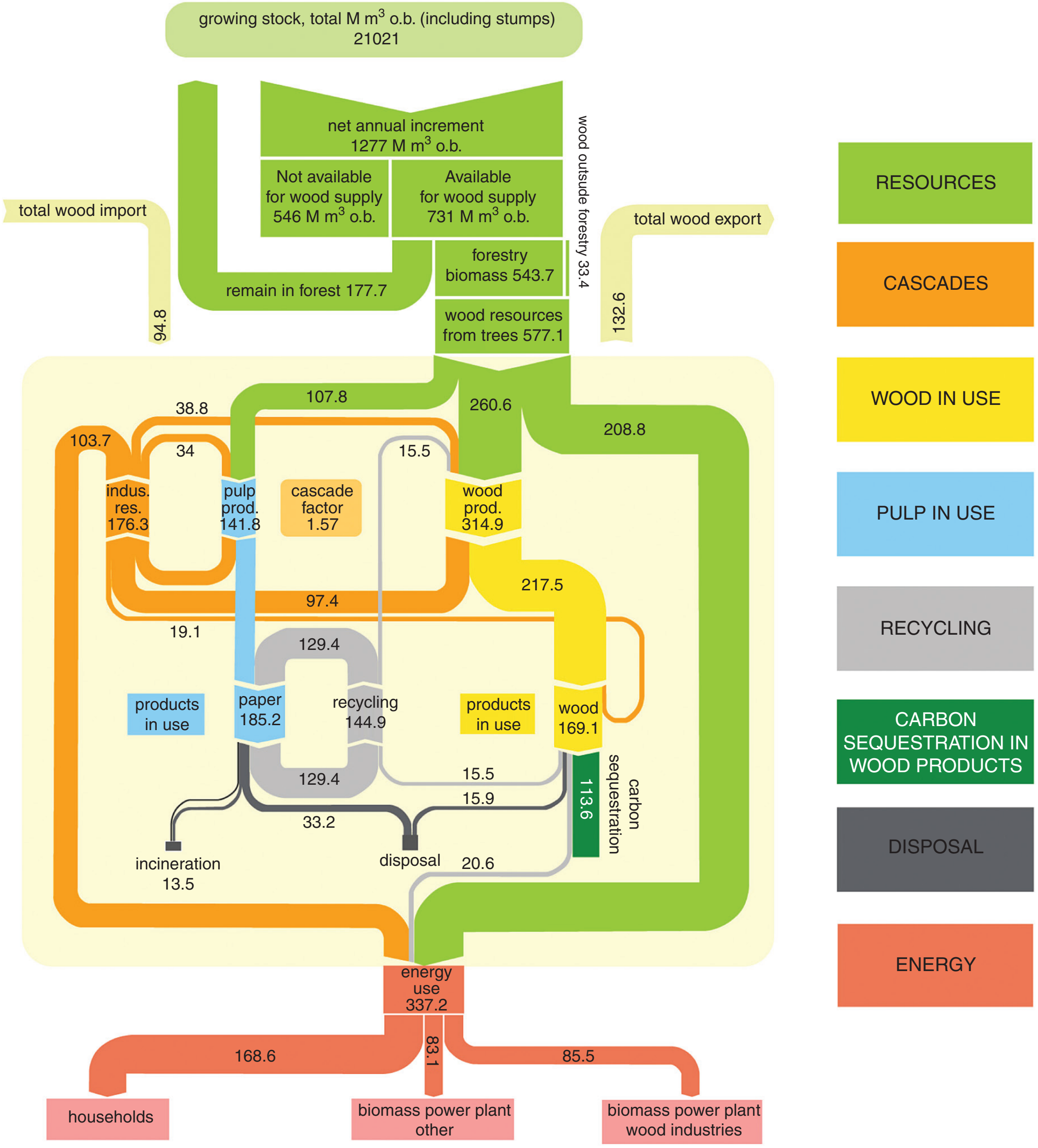

*Figure 1.2 Overview of the use of wood in the EU. Source: redrawn from Mantau (2012). Values are in cubic metres of solid wood equivalents.*

The main current uses of forest products and services can be divided into several categories, as shown in Figure 1.2, where the flow starts with the harvest from the growing stock, proceeds through processing to main products of saw wood and paper, with a substantial flow also to bioenergy. Overall, European wood is used in almost equal proportions (40%) for energy and products. The remaining 20% is used for pulp.

### *1.2.1 Use of wood for the production of goods*

Traditional EU forest industries are based on pulp (paper, board) and wood products (saw wood, wood-based panels, engineered products). These traditional markets (especially in printing paper) have been declining through global competition, although recently this trend may have stabilised or even reversed. Emerging new forest industries are seen in some Member States supplying the 'bioeconomy', where resources such as lignocellulose in timber are used as feedstocks for chemicals, materials and biofuels. Future prospects for a cost-effective bioeconomy realising its full potential depend on the technological development of biorefineries (Box 3) and an integrated approach for the co-production of value-added products such as biomaterials, biochemicals, bioplastics, food and feed at the same time as bioenergy (including liquid biofuels, biogas, and biomass-generated heat and/or electricity).

**Box 3 Biorefining**

Biorefining is defined by the International Energy Agency (IEA, 2016) as the sustainable processing of biomass into a range of bio-based products (food, feed, chemicals and materials) and bioenergy (biofuels, power and/or heat). The purpose is to use the raw material in the wood as a chemical feedstock to produce high value chemicals (for example fine chemicals, pharmaceuticals, polymers) and secondary energy carriers (transport fuels such as bioethanol, biogas). Outputs are thus considerably higher up the value chain than just using the biomass for generating heat and/or electricity.

Major chemical components of woody biomass include lignin and sugars, and a range of biological, chemical, physical and thermal processes can be applied to produce biochemicals and fuels. Typical processes include fermentation, biocatalysis, gasification and pyrolysis. Major product streams depend on the chosen biorefining platform and the respective technologies but may include bioethanol, biogas (methane), biochemicals, bioplastics and foodstuffs. Potential industries to which biorefinery products can contribute include the food, electronic, medical and clothing industries. In general, both energy-driven and product-driven biorefineries can be distinguished.

The concept of the biorefinery is still in early stages and has attracted government support for innovation in some countries. As one example, Sweden's Domsjö Development area biorefinery produces several products with applications in viscose production, chemicals, fuels, paints and construction materials. The Swedish Government is supporting the development of an innovation cluster to develop the technical and economic viability of a range of biorefining processes. In Finland, biorefining to produce bio-liquid and biogas transport fuels constitutes a significant part of the national 2016 Energy and Climate Policy (Box 7 in Chapter 5).

A key requirement for any biorefinery development is a large supply of biomass from nearby areas to supply the necessary feedstock, which can conflict with other objectives (for example biodiversity or carbon storage targets). Furthermore, to ensure biorefining contributes to reducing atmospheric carbon dioxide levels, biomass-based products should substitute for existing oil-based production; and ultimately replace some petrochemical refineries (De Jong and Jungmeier, 2015).

### *1.2.2 Use of wood for bioenergy (substituting for fossil fuels)*

Biomass has been widely promoted as a source of 'renewable' energy, and most EU Member States have put in place incentives to encourage its use as a substitute for fossil fuels to generate electricity and/or heat. Underlying this is the EU's commitment to decarbonisation of the energy sector, which requires a switch from fossil fuels to low-carbon renewable sources of energy. More specifically, EU Member States have made binding commitments to provide 20% of their energy from renewable sources by 2020 and a collective commitment to provide at least 27% by 2030. Biomass is currently a major component of the strategy to meet these 2020 and 2030 targets, and over 50% of 'renewable' energy in the EU currently originates from biomass. Some 40% of the annual harvest from EU forests is ultimately (as by-products or post-consumer waste) used for bioenergy (Figure 1.2). Current expectations are that biomass will continue to play an important role in meeting EU energy and climate targets, with forests as a principal contributor. Issues associated with forest biomass use for bioenergy and electricity generation are further discussed in Chapter 4.

### *1.2.3 Use of forests in climate change mitigation by removing carbon from the atmosphere*

The basic role of forests as a sink and source of carbon dioxide are summarised in Box 4. Forests contribute to the global atmospheric carbon dioxide concentration by both sequestering and emitting greenhouse gases (GHG). Global anthropogenic (human-induced) emissions amounted to about 50 gigatonnes of $CO_2$-equivalent (Gt $CO_2$e)[6] in 2010, approximately one-quarter (12 Gt $CO_2$e) of which originated from agriculture and forests. Current initiatives to reduce emissions globally are insufficient to prevent global temperatures from increasing by more than 2 °C above pre-industrial levels (Rogelji *et al.*, 2016), and the emission mitigation actions proposed in the 2015 United Nations Climate Change Conference in Paris (also known as twenty-first session of the Conference of the Parties, COP21) Intended Nationally Determined Contributions still leave a significant emissions gap. It is thus important to determine to what extent forests could be used to reduce this gap.

Climate change mitigation via forests requires three interlinked actions: first, increasing the share of wood-based products with long lifetimes (for example building materials) and the use of wood as a substitute for fossil fuels *where this delivers a net benefit to the atmospheric carbon budget*; second, increasing the GHG-efficiency of the production of wood-based products; and third, increasing the rate of carbon storage and the size of carbon stocks in forests and forested land. The Intergovernmental Panel on Climate Change (IPCC) estimated the potential from the forestry sector globally as 2.7 Gt $CO_2$e per year (IPCC, 2007), while the EU has suggested that GHG mitigation and adaptation in the (EU) land sector could abate between 0.32 and 0.35 Gt $CO_2$e per year by 2030 (JRC, 2016). This will be discussed further in Chapter 2.

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[6] Units in assessing global warming effects can be based on carbon emissions (tonnes of carbon: t C), carbon dioxide (tonnes of $CO_2$: t $CO_2$) or also include emissions of other GHG, making allowance for their different global warming potentials (tonnes of $CO_2$ equivalent: t $CO_2$e).

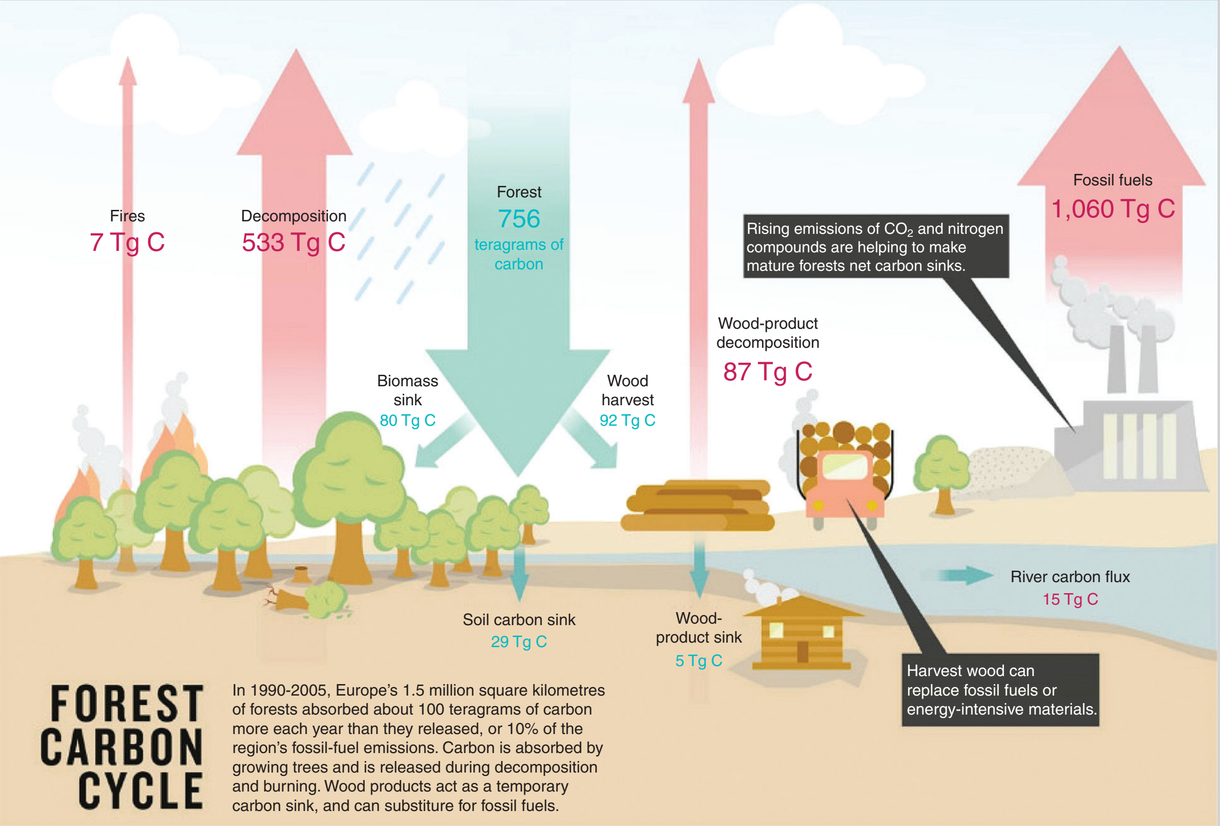
### Box 4 Forests as sinks and sources of carbon dioxide

Forests perform an important function by removing carbon dioxide from the atmosphere through photosynthesis. Globally, land ecosystems (including forests, agricultural lands, etc.) remove about 30% (9.5 ± 2.9 Gt $CO_2$/yr) of anthropogenic carbon dioxide emissions, demonstrating the significance of forests' role in mitigating the accumulation of carbon dioxide in the atmosphere (Houghton *et al.*, 2012; Giglio *et al.*, 2013; Le Quéré *et al.*, 2015). The net forest carbon sink is the balance between carbon inputs (photosynthesis) and carbon outputs. In the case of a net sink, the carbon inputs exceed the outputs, resulting in storage of carbon (1 $m^3$ of wood stores ≈ 0.92 t $CO_2$). The outputs are determined by three main pathways: respiration (50%; Luyssaert *et al.*, 2007), decomposition (36%; Luyssaert *et al.*, 2010), and removal of the carbon from the site through harvest, fire, run-off and leaching (7%). Globally, terrestrial carbon uptake has been increasing over recent decades, one significant reason being the combined effects of rising carbon dioxide concentrations on photosynthesis (the carbon dioxide fertilisation effect) and, in the past decade, a slowdown of global respiration in response to warming (Keenan *et al.*, 2016). At present in the EU, the net forest carbon sink (i.e. the rate of carbon storage increase) amounts to 7% of the carbon input to the ecosystem (Luyssaert *et al.*, 2010) and is stored in the soil and in below- and above-ground biomass. The ratio between above- and below-ground storage is important for the longevity of the carbon sink and varies as a function of nutrient availability and management (Vicca *et al.*, 2012; Fernández-Martinez *et al.*, 2014; Campioli *et al.*, 2015). In practice, managed forests on nutrient-rich sites offer the highest carbon sink.

Forest carbon dynamics are characterised by long periods of slow carbon uptake, interrupted by short periods of rapid and large carbon releases during disturbances or harvest. Depending on the stage of stand development, individual stands are either carbon sources or carbon sinks. For most stages of stand development, stands are carbon sinks. While individual stands in a forest may be either sources or sinks, the forest landscape carbon balance is determined by the sum of the net balance of all stands. The theoretical maximum carbon storage (saturation) in a forested landscape is attained when all stands are in an old-growth state, but this rarely occurs since natural or human disturbances maintain stands of various ages within the forest.

Even in very old forests, ecosystem carbon storage will still continue to increase slowly with accumulations; mostly in dead organic matter and soil carbon pools. In the years following major disturbances, the losses from decay of residual dead organic matter exceed the carbon uptake through regrowth. Even though old forests often have a lower rate of carbon absorption than young forests, they store a larger amount of carbon over their whole life cycle (Schulman, 1954; Luyssaert *et al.*, 2008; Hudiburg *et al.*, 2009; Bugmann and Bigler, 2011; Bigler and Veblen, 2009).

The annual increment of wood in the forests of the 28 EU Member States amounts to 720 million $m^3$ (Forest Europe, 2015). This translates into a gross uptake of about 756 million tonnes (teragrams (Tg), $10^{12}$ g) of carbon annually (Luyssaert *et al.*, 2010). After accounting for harvest and losses from decomposition, 100 million tonnes of carbon is sequestered annually; this represents the carbon that is removed from the atmosphere and for Europe is equivalent to about 10% of its fossil fuel emissions (Nabuurs *et al.*, 2003, 2015; Luyssaert *et al.*, 2010; Tupek *et al.*, 2010). A summary of these flows is shown in the figure below (Bellassen and Luyssaert, 2014).



Rising emissions of $CO_2$ and nitrogen compounds are helping to make mature forests net carbon sinks.

Harvest wood can replace fossil fuels or energy-intensive materials.

In 1990-2005, Europe's 1.5 million square kilometres of forests absorbed about 100 teragrams of carbon more each year than they released, or 10% of the region's fossil-fuel emissions. Carbon is absorbed by growing trees and is released during decomposition and burning. Wood products act as a temporary carbon sink, and can substiture for fossil fuels.

*Forest and soil carbon stocks and flows in Europe.*

### 1.2.4 *Other forest-based ecosystem services: biodiversity conservation, recreation, etc.*

In several countries, forest ecosystems provide mushrooms, berries and other benefits to local people; 65 million EU citizens collect wild food (Schulp *et al.*, 2014). Biodiversity conservation, i.e. the combined goal of protecting habitat, species and genetic diversity, is an important function of forested land, and intimately linked to many other functions that forests deliver. A large part of the European fauna and flora depends in full or in part on forests, and trees and forests are part of our cultural and historical heritage.

Biodiversity in forests is in decline[7] and very few biodiversity 'hotspots' such as old-growth forests remain in Europe. Climate change and forest management are major threats for conservation areas and biodiversity (Araújo *et al.*, 2011), with 58–63% of European plant and terrestrial vertebrate species projected under climate change scenarios to lose suitable climate niches (even in protected areas) by 2080. The EU biodiversity strategy to 2020 includes among its targets an increased contribution of forestry to biodiversity. The adoption of genuinely SFM is expected in public forests, and to be encouraged in private holdings via subsidies to reward actions towards biodiversity conservation objectives.

## 1.3 EU forest policies and their relationships to international agreements

In the EU, forest policies remain the competence of Member States within various frameworks of ownership rights and national and regional laws and regulations. Increasing attention has been paid to the sustainability of forestry management under accreditation schemes such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). The EU Forest strategy in 2013 aimed also to integrate forest use with climate change and agricultural policies, although implementation remains the responsibility of Member States (EC, 2013). This dependency on national competencies is in contrast to the increasingly global scale of related policy issues such as climate change mitigation and biodiversity conservation, and makes achieving EU level synergies challenging.

The EU already recognises the interaction of different policy objectives within the common theme of 'forests': in regional wealth creation and employment, natural resources and raw materials, nature conservation and biodiversity, climate change and energy policy and agriculture. Consequently, the many Directorates-General of the European Commission, which are responsible for policies that are linked to forests, face a significant challenge to ensure a systematic approach, to avoid conflicts and to enhance sustainability and synergies between different policy domains.[8]

In addition to national and EU level policies, the UN Conventions on climate change and on biological diversity have a direct link with several EU activities; for instance the following:

- *Climate change*: UNFCCC; 2009 Renewable Energy Directive (RED); 2011 Low Carbon Economy Roadmap; 2013 Decision on GHG emissions and removals; 2030 Climate and Energy Framework; 2016 Ratification of the Paris Agreement; inclusion of greenhouse gas emissions and removals from LULUCF into the 2030 Climate and Energy Framework (20 July 2016); November 2016 package on 'Clean Energy for All Europeans'.

- *Biodiversity*: United Nations Convention on Biological Diversity; Birds Directive 1979; Habitats Directive 1992; Alien Species Regulation 2014; Biodiversity Strategy 2011-2020; Mid-term review of EU Biodiversity strategy (Dec 2015).

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[7] According to EEA (2016), only 26% of forest species and 15% of forest habitats of European interest, as listed in the Habitats Directive, were in 'favourable conservation status' in 2007–2012, and 27% of mammals, 10% of reptiles and 8% of amphibians linked to forest ecosystems are considered to be under threat of extinction within the EU.

[8] Although there is no common forest policy at EU level, dialogue and cooperation on forest policies has existed since 1990 within Forest Europe (The Ministerial Conference on the Protection of Forests in Europe) to develop common strategies on how to protect and sustainably manage forests at the European scale.

# 2 Forests and climate change

As the international community has moved within the UNFCCC to address global warming and climate change, the role of forests has received much scrutiny. Most recently, the 2015 agreement at UNFCCC COP21 (Paris Agreement) acknowledges the need for SFM and the enhancement of forest carbon stocks. This in turn requires those who are responsible for defining and implementing forest management practices to have a detailed knowledge of how forests and their management may contribute to carbon capture and storage, to GHG emissions or other impacts. The radiative forcing factors[9] that are particularly relevant to forestry are shown in Figure 2.1, where it can be seen that the impacts of forests on global average temperatures can be positive or negative and are not all fully accounted for in current policies.

## 2.1 Climate change and impacts on European forests' vitality

The effects of climate change on forests are very different in the various parts of Europe (EEA, 2017). They are already visible in Mediterranean and Alpine areas through an increase in tree mortality (Bréda *et al.*, 2006; Dobbertin *et al.*, 2007) and species shifts (Hlásny *et al.*, 2011; Rigling *et al.*, 2013). In contrast, in the continental and boreal zones of Central and Northern Europe, forest growth rates have increased owing to the elevated atmospheric carbon dioxide concentrations increasing the photosynthesis rate of plants, as well as longer growing seasons and nitrogen deposition (Lindner *et al.*, 2014; Pretzsch *et al.*, 2014; Donohue *et al.* 2013; Zhu *et al.* 2016). In combination with stable harvest rates, these changing environmental conditions have led to increased carbon stocks in these areas.

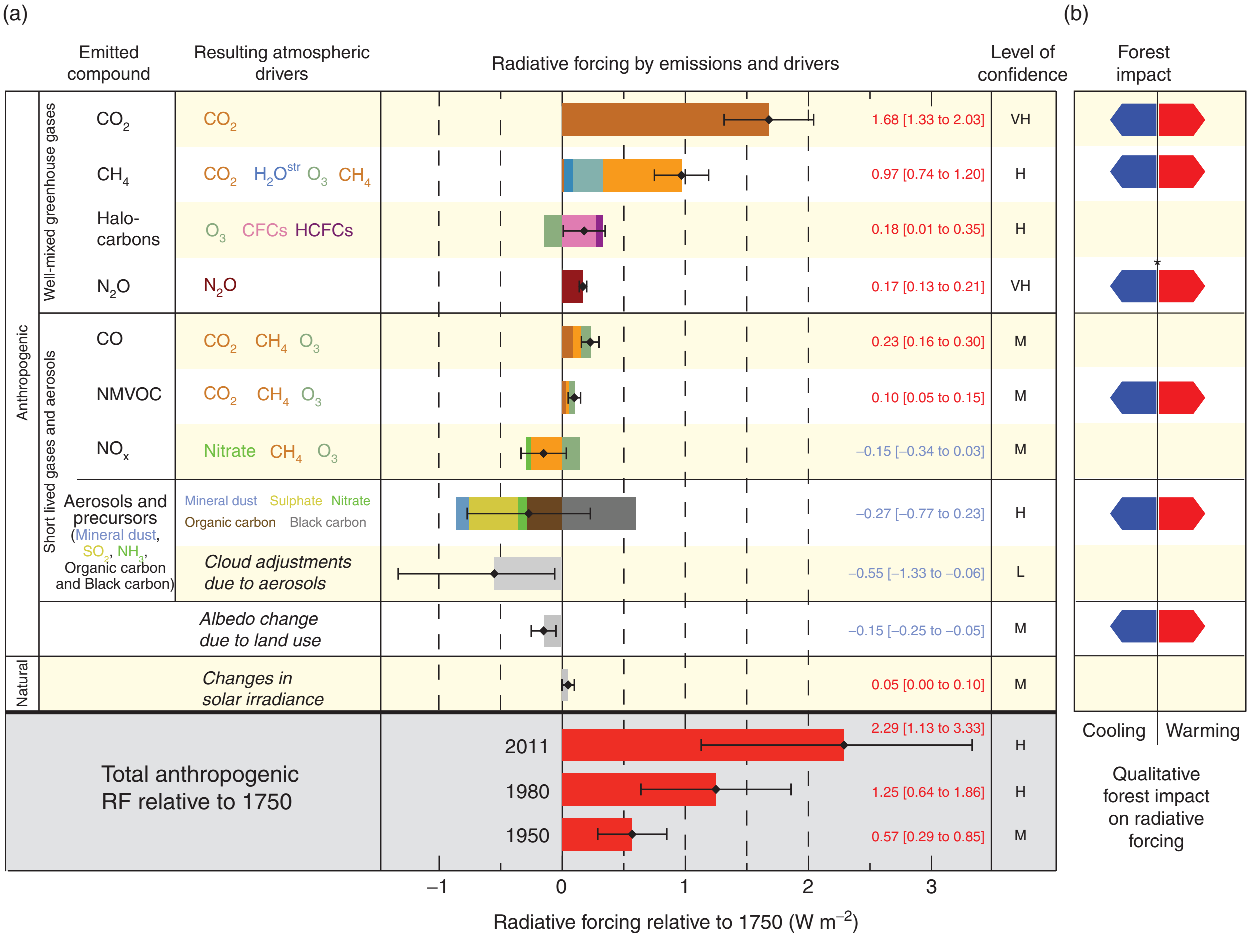

*Figure 2.1 The relation between radiative forcing (RF) drivers, the influence of global forests and whether this is accounted for in current EU policies (adapted from Figure SPM.5 in IPCC (2013)). (A) The role of atmospheric components in warming or cooling. Values show global radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Negative/blue values indicate cooling; positive/red, warming. Level of confidence: VH, very high; H, high; M, medium; L, low. NMVOC, non-methane hydrocarbons. (B) The qualitative impact of forests on atmospheric components that have an influence on warming. Note that the impact of forests can be either cooling or warming the climate, depending on the management options chosen.*

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[9] Radiative forcing is the capacity of a gas or other forcing agent to affect the energy balance from the sun.

In general, forest growth is projected to continue to increase in Northern Europe and to decrease in Southern Europe, but with substantial regional variations. For example, some cold-adapted, coniferous trees are estimated to lose large fractions of their ranges to more drought-adapted broadleaf species. Further, under future climate scenarios, increased mortality may lead to large areas where forests will be replaced by other vegetation (Allen *et al.*, 2010), and if current warming trends remain unabated, scenarios to 2100 suggest the likelihood of major shifts north in the current forest types (Hanewinkel *et al.*, 2013) as a result of changes in temperature and precipitation, with severe economic consequences.

Extreme storms cause significant damage to Central and Western European forests (Schelhaas *et al.*, 2003; Lindroth *et al.*, 2009; Gardiner *et al.*, 2010), and since the 1990s have damaged hundreds of millions of cubic metres of timber (Usbeck *et al.*, 2010). Storm damage (the combination of strong winds, heavy rains and extended growing seasons for deciduous trees) not only affects timber production, but simultaneously disrupts carbon sequestration and releases stored carbon to the atmosphere (Lindroth *et al.*, 2009). In addition, it often leads to follow-up damage by insects that may spread to other forest areas. At the same time, the damaged wood is an important resource for the many dead-wood-dependent species, and storm damage can thus have both negative and positive effects. Increases in extreme weather (EASAC, 2013) require forestry management strategies to adapt in areas affected by heavy winter storms. In Mediterranean areas, climate change is contributing to drought stress, which may lead to an increase in wildfires as well as infestations by insects.

Overall rates of damage are shown in Figure 2.2, where it can be seen that damage from wind, bark beetles and wildfires have increased between 1971 and 2010, although the extent of damage is still only a few per cent of the EU forest area. Using an ensemble of climate change scenarios, further increases are predicted of 0.91 million $m^3$ of timber per year until 2030.

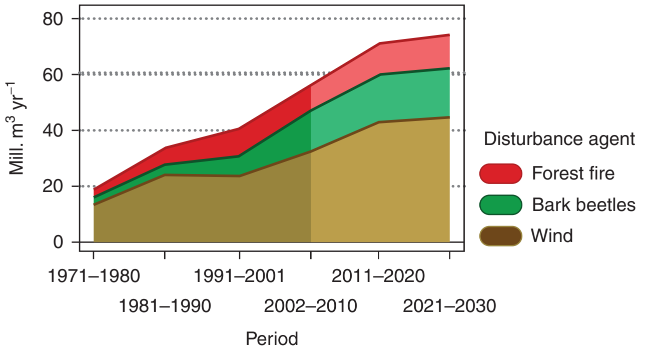


*Figure 2.2 Recent trends and future forecasts for forest damage in the EU (Seidl et al., 2014).*

This increasing trend has been attributed to both climate change and changes in forest structure through management, so that adaptive management (see Chapter 5) could partly mitigate forest damage with a stronger focus on disturbance risk and resilience (Seidl *et al.*, 2014).

Designing forest regeneration schemes to take into account local conditions is an important tool for storm damage mitigation. A shortening of rotation times may in some regions increase resilience towards storm and insect damages, as tall evergreen trees on shallow soils are often more vulnerable—especially in an even-aged forest with homogenous stand structure (Meilby *et al.*, 2001; Gardiner *et al.*, 2010; Hale *et al.*, 2015; Schmidt *et al.*, 2010). However, there are trade-offs with carbon storage and biodiversity, which can be increased by lengthening the rotation period (Yousefpour and Hanewinkel, 2009), as discussed further in section 2.2 and Chapter 3.

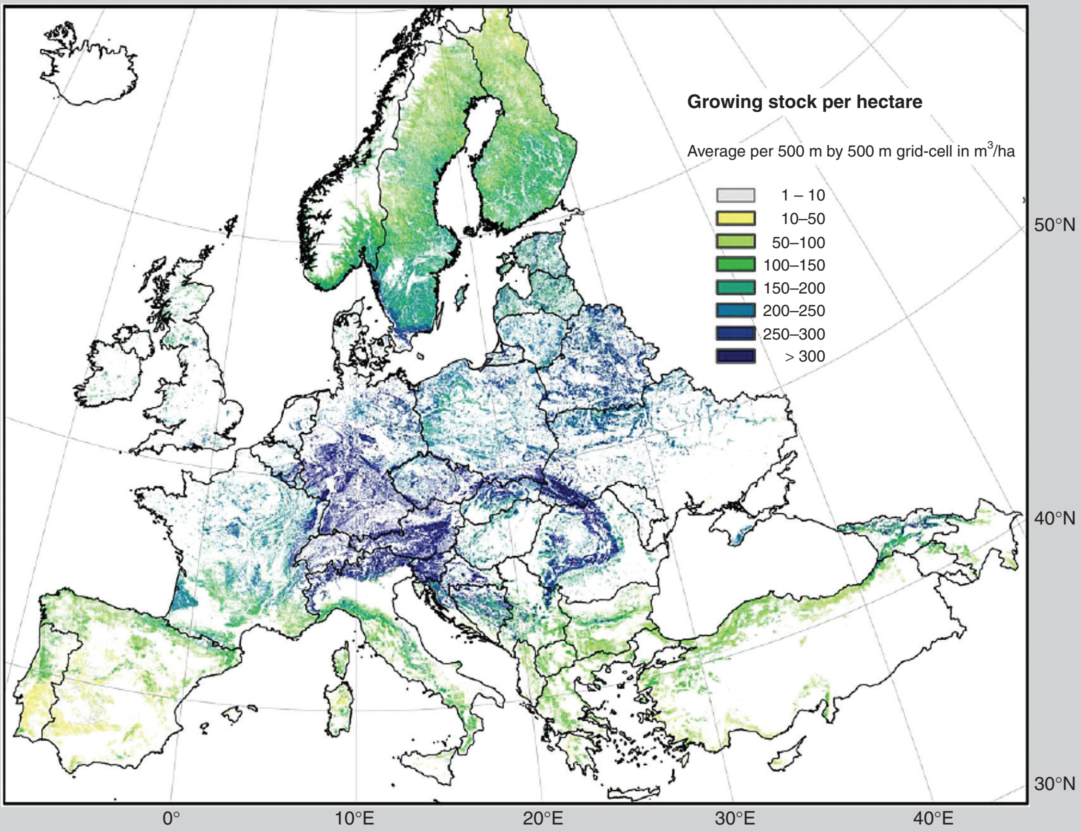
Forest vitality and resilience are fundamentally linked to the genetic diversity of forest stands (Koskela and Lefèvre, 2013). Tree populations with a high level of genetic diversity have a better chance of defending themselves against pests (Müller-Starck, 1995). In this context, genetic diversity not only increases the likelihood that the population will persist, it also forms the basis for adaptation of species over the longer term. Monocultures developed from a narrow genetic basis are likely to be more susceptible to pests and diseases—especially if they are based on clones. Species richness is also important for the resilience of the ecosystem as a whole (Fares *et al.*, 2015). Since 30% of forest stands in Europe are dominated by one tree species (mainly conifers), forest management options ranging from mixed native species plantations to continuous cover forestry offer the potential to increase resilience by increasing species diversity (see also Chapter 3). For longer-term climate change scenarios (Hanewinkel *et al.*, 2013) of major declines in some economically important species such as Norway spruce and European beech, potential adaptation measures include new, better drought- and heat-adapted species or varieties, assisted migration of tree species to areas where they may be better adapted, traditional breeding or genetic modification, and gene conservation. However, potential harmful effects of such management tools on biodiversity and other ecosystem services need to be assessed before adoption.

## 2.2 Forests as sinks and stocks of carbon

A summary of current trends in the amounts of carbon stored in Europe's forests is given in Box 5. Clearly, enhancing the role of forests as carbon sinks requires forests to be resilient to climate-change-related impacts that could release the sequestered carbon back into the atmosphere. Forest management approaches and

## Box 5 Carbon stocks and forest carbon sinks

As described in Box 4, forests remove carbon from the atmosphere and store it in biomass and soil, thereby contributing to climate change mitigation. Carbon stocks across Europe vary widely, both locally and across countries, and are determined by climate, soils, tree species, management history, etc. (see figure below).



*Growing stock of stemwood in cubic metres per hectare for a 500-m × 500-m resolution of European forests (Gallaun et al., 2010).*

Harvesting intensities vary a lot between and within Member States (Barredo *et al.*, 2012), and forest carbon storage is currently increasing over large parts of Europe (Nabuurs *et al.*, 2003) owing to harvesting less than the annual wood increment (Forest Europe, 2015), carbon dioxide fertilisation (Norby *et al.*, 2005, Donohue *et al.*, 2013, Keenan *et al.*, 2016, Zhu *et al.*, 2016), warming (Myneni *et al.*, 1997; Luo, 2007), increasing stand density by suppressing fire and abandoning grazing (Rautiainen *et al.*, 2011), nitrogen deposition from burning fossil fuels and from agricultural fertiliser use (Magnani *et al.*, 2007), decreasing nutrient harvest by abandoning litter raking and grazing (Spiecker *et al.*, 1996; Gimmi *et al.*, 2013), large-scale afforestation (Nilsson and Schopfhauser, 1995) and natural succession following land abandonment (Olofsson *et al.*, 2011; Fuchs *et al.*, 2015; Kuemmerle *et al.*, 2015).

Because conditions in different parts of Europe vary and interactions are not fully understood (Hyvönen *et al.*, 2007), it is unclear for how long the carbon sink in EU forests will continue to increase, especially since historical records show carbon storage in Europe to have been significantly lower (Kaplan *et al.*, 2012). In this context, Nabuurs *et al.* (2013) have reported the first signs of carbon sink saturation in European forest biomass. Moreover, growth in some species (especially beech) has been reversed in recent years (Kint *et al.*, 2012). Nevertheless, there may be potential for increasing the carbon sinks and stocks in currently managed forests by changing management practices to encourage higher levels of standing biomass (at least in some regions).

planning are particularly important for controlling the carbon balance as the climate changes (Garcia-Gonzalo *et al.*, 2007; Mäkipää *et al.*, 2011, 2015) and for reducing the risk of large-scale forest dieback.

Owing to socio-economic changes in rural areas, some agricultural lands in Europe have been abandoned, following which afforestation often occurs either through natural succession or deliberately.[10] Afforestation of degraded (or marginal) lands has also been suggested as a means of increasing forest carbon stocks, and studies indicate that the global effects of afforestation on GHG-management could be substantial in terms of additional carbon dioxide sequestration

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[10] Planned or deliberate afforestation was estimated at 1.5 million hectares (Mha) whereas successional afforestation resulted in 11.4 Mha of new forests between 1990 and 2015 alone (UNECE/FAO, 2011; Forest Europe, 2015).

(Nabuurs *et al.*, 2007), although it may take several decades before the biomass stocks in vegetation and soils of the newly planted forests exceed those present before the land was converted (Nabuurs *et al.*, 2009).

However, land taken for afforestation (planned or successional) could conflict with other policy objectives such as food production, conserving biodiversity and sustaining a minimal river discharge (Jackson *et al.*, 2005). The different climatic conditions in EU countries and balancing demands for land between forests lands, grasslands and wetlands may also affect the potential for afforestation. Indeed, what are sometimes regarded as marginal lands can be grasslands of high nature value (Burrascano *et al.*, 2016), which are considered to be important for biodiversity conservation and contain high soil carbon pools. Such afforestation may thus decrease biodiversity as well as involving long delays before a net reduction in carbon emissions is achieved. Taking these factors into account, it has been estimated that some 15 million hectares of abandoned farmland in the EU could be available for planned afforestation up to 2030 (Keenleyside and Tucker, 2010).

Nabuurs *et al.* (2015) have proposed the concept of 'climate smart forestry' policy, which would aim to increase forest productivity and incomes by adapting and building resilience to climate change, and by reducing and/or removing GHG emissions. Components would include tax incentives for regeneration with more resilient trees, using wood in place of more carbon-intensive products (for example steel or concrete), carbon dioxide credits and other payments for ecosystem services. Through such policies, it was estimated that EU forests, their wood supply chain and energy contributions could compensate for up to 20% of total EU fossil fuels emissions (Nabuurs *et al.*, 2015). However, the overall climate impacts of climate smart forestry have not yet been fully evaluated, nor the compatibility between shifting to climate-resilient species and market demands.

## 2.3 Accounting for all climate impacts of forestry

The climate effect of forest management via the carbon balance is supplemented by the biophysical effects (Pielke *et al.*, 2002; Jackson *et al.*, 2008) of albedo, forest structure, evapo-transpiration, and the release of volatile organic compounds and microbes from plant surfaces capable of forming aerosols and subsequently clouds (Ellison *et al.*, 2017). In addition, other GHG (such as methane and nitrous oxide from wetlands and forest with wet soils) may contribute significantly to climate warming (Figure 2.1), although management options such as drainage and wetlands management can reduce their contributions locally. In tropical regions, the GHG and biophysical effects of a forest tend to work together to cool the land surface (Baidya and Avissa, 2002; Jackson *et al.*, 2008; O'Halloran *et al.*, 2012). However, in areas with substantial snow cover, the GHG sequestering effect of afforestation is easily offset by the biophysical effects whereby reduced snow cover reduces reflection of solar radiation back to space (Randerson *et al.*, 2006; Jackson *et al.*, 2008; Lee *et al.*, 2011). The transitional latitude where afforestation and forest management choices contribute to climate cooling rather than to climate warming is located in the temperate zone, but its exact location is subject to ongoing scientific debate (Li *et al.*, 2015; Alkama and Cescatti, 2016). The transitional latitude falls within the European domain, so cases where biophysical effects either strengthen or counteract GHG effects can be expected to occur. Indeed, Naudts *et al.* (2016) showed that the overall effects of European forest management on climate between 1750 and 2010 were a small warming rather than the commonly assumed substantial cooling.

Biophysical effects can, in some circumstances, be of similar magnitude to the net effects of changing the carbon balance through afforestation or deforestation (Luyssaert *et al.*, 2014); warming effects through albedo changes may be offset by the potential cooling effects of forest-originating aerosols (Kulmala *et al.*, 2014, Teuling *et al.*, 2017). Ellison *et al.* (2017) reviewed the effects of trees and forests as prime regulators within the water, energy and carbon cycles and suggest they should be managed to increase their contribution to climate cooling through hydrological mechanisms and not just from a carbon-centric perspective. The accumulating evidence thus suggests that ignoring biophysical interactions – as is currently the case in the Kyoto Protocol and the Paris Agreement – could result in mitigation projects that provide little climate benefit or, in the worst case, are counter-productive (Marland *et al.*, 2003; Jackson *et al.*, 2008; Naudts *et al.*, 2016).

While accounting for biophysical effects is difficult, current evidence suggests that in the boreal and temperate zones, the net effects of deciduous species are likely to lead to cooling, whereas the net effects of evergreen species are more difficult to quantify (Zhao and Jackson, 2014; Matthies and Valsta, 2016). Preferential use of mixed evergreen–deciduous stands (Northern EU countries) or deciduous stands (Central Europe) could be a reasonable strategy for climate change mitigation based on current evidence related to biophysical effects.

# 3 Forests and biodiversity

## 3.1 Forest biodiversity and ecosystems services

Protecting biodiversity is an aim in itself under the CBD and EU Biodiversity Strategy but is also highly significant in the context of ecosystem functions and the associated benefits people obtain from ecosystems (Díaz *et al.*, 2015a). Generally, three categories of ecosystem services are distinguished: *provisioning services* provide food, fuel, genetic resources, water and energy; *regulating and maintenance services* secure climate regulation, protection against natural hazards such as floods and erosion, pollination, etc.; and *cultural services* maintain recreation activities, aesthetic, religious and spiritual experiences (Haines-Young and Potschin, 2013). Biodiversity, as one of the most important ecosystem condition indicators, enables ecosystems to provide services. Without the maintenance of good ecological condition and biodiversity the preservation of services cannot be achieved.

In the case of forests, FAO (1997) includes the following examples of ecosystem services.

- Regulation of water regimes by intercepting rainfall and regulating its flow through the hydrological system.
- Maintenance of soil quality and the provision of organic materials through leaf and branch fall.
- Limiting erosion and protecting soil from the direct impact of rainfall.
- Modulating climate.
- Providing the raw material for a variety of industries including timber, processed wood and paper, energy and fruits/nuts.
- Products used by rural agricultural communities (fuel and fodder, grazing, game, fruits, building materials, medicines and herbs).
- A key component of biodiversity both in themselves and as a habitat for other species.
- Socio-cultural services—many people have strong cultural and spiritual attachments to forests. Many local people understand how to conserve and use forest resources.
- Scenic and landscape services and values- aesthetics and beauty as components of services of forests—both from the perspective of tourism and of importance to residents.

Several studies underline the critical role of biodiversity in the supply of ecosystem services (Hooper *et al.*, 2005; Balvanera *et al.*, 2006; Luck *et al.*, 2009; TEEB, 2010; Bastian, 2013;). A decline in biodiversity threatens the ability of both managed and natural ecosystems to adapt to changing conditions and hampers the provisioning of ecosystem services (Bellard *et al.*, 2012; Díaz *et al.*, 2015a; 2015b). A recent meta-analysis (Liang *et al.*, 2016) reviewed global forest data from more than 770,000 sample plots in 44 countries and found a positive and consistent relationship between tree diversity and ecosystem productivity at landscape, country and eco-region scales. According to that study, an average 10% loss in tree species diversity leads to a 3% loss in productivity, which equates to a global economic value of US$166 billion to US$490 billion per year—over five times the expenditures on global conservation.

Forests are a critical habitat for many species and a major contributor to biodiversity at both global and European levels. At the global level, biodiversity is in decline, with the Living Planet Index (a measure of the state of the world's biological diversity of vertebrates) showing a decline of 52% between 1970 and 2010 (WWF, 2016). The European Red Lists identify the species that are threatened with extinction at the pan-European and EU level[11]: 15% of Europe's 231 mammal species are threatened, and a further 9% are close to threatened status, with habitat loss and degradation being the greatest drivers of decline (Temple and Terry, 2007). Nineteen per cent of Europe's 488 bird species are threatened or near threatened, with biological resource use (including forestry) and agriculture and aquaculture being the main drivers of endangerment (Gregory *et al.*, 2007; Lehikoinen and Virkkala, 2017). Of the plants that have been assessed for the whole of Europe, 25% are threatened with extinction (Bilz *et al.*, 2011). Red Lists of forest species include saproxylic beetles where 14% (57 species) are threatened in EU countries and a further 13% considered near threatened (Nieto and Alexander, 2010). Furthermore, 14% of habitats and 13% of species of European interest are assessed as being under pressure because of climate change (EEA, 2017), and habitats threatened by climate change are projected to more than double in the near future.

Forest Europe (2010) assessed the implementation of the CBD and proposed pan-European Indicators for SFM including nine biodiversity indicators (tree species composition; regeneration; naturalness; introduced tree species; deadwood; genetic resources; landscape

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[11] http://ec.europa.eu/environment/nature/conservation/species/redlist/

pattern; threatened forest species; protected forests). Guidance is already provided in some Member States on enhancing biodiversity through SFM. For instance, UK Forestry Standard Guidelines on biodiversity include consideration in SFM of priority habitats and priority spaces; native woodlands; landscape ecology; ecological processes; tree and shrub species selection; veteran trees and deadwood; open scrub and edge habitats; riparian zones; habitat creation and restoration; dealing with invasive species; and the use of grazing and browsing (Forestry Commission, 2011).

## 3.2 The importance of forest structural elements, old-growth forests, and forest continuity for biodiversity

The forests in the EU are diverse and complex, and biodiversity conservation in forests differs between regions. Here we concentrate on a few central issues for EU-wide policy, which also coincide with megatrends driving global biodiversity decline—particularly the reduction of habitats and the deterioration or degradation of habitat conditions.

Conventional logging using uniform shelterwood or clear-cutting systems is practised across Europe and leads often to homogenous stands with reduced quantities of standing deadwood and logs, an even-aged structure, and a lack of rare woody species and large veteran trees (Woodcock *et al.*, 2015). Some recent efforts have emerged to introduce novel techniques such as retention forestry (Gustafsson *et al.*, 2012) and to adjust clear-cutting and shelterwood management, but forest management and utilisation remain key factors limiting the biodiversity of Europe's forests (EEA, 2008, 2016). Moreover, pressures to extract more wood from forests typically lead to reduced population sizes of the species dependent on forest cover continuity, deadwood and large trees and, in the worst case, local extinctions (Brunet *et al.*, 2010; Paillet *et al.*, 2010).

Except for a few habitats dominated naturally by one or two tree species, natural forest ecosystems usually contain several woody species. Such multi-species forest habitats provide higher levels of ecosystem services (productivity and biomass included) than forests with one or a few tree species, as no single tree species is able to provide all ecosystem services (Balvanera *et al.*, 2013; Gamfeldt *et al.*, 2013; Tilman *et al.*, 2014). In spite of this, mainly as a consequence of maximising volume yield in timber production, one-third of European forest stands are dominated by only one tree species, and only 20% harbour more than three species (Nabuurs *et al.*, 2015).

The most important structural elements for biodiversity in forests are standing and lying dead trees, hollow trees, rare woody species and large veteran trees (Bauhus *et al.*, 2009; Brunet *et al.*, 2010); large living trees and high amounts of deadwood form the basis for a significant part of forest biodiversity (Peterken, 1996; Larsson, 2001; Stokland, 2001; Bobiec, 2002; Bartha *et al.*, 2006; Burrascano *et al.*, 2013). Large trees that provide microhabitats such as cracks, bark injuries, crown dead wood (so-called habitat trees) are essential for many Natura 2000 species including epiphytes and several birds of prey. Standing dead trees or trees weakened by fungi provide habitat for almost all cavity-nesting birds, such as woodpeckers, several song birds, and for forest-dwelling bats and mammals (Bobiec, 2005), and a whole range of endangered saproxylic beetles are dependent on these forest elements (Nieto and Alexander, 2010; Müller *et al.*, 2014). The volume of dead wood per hectare has thus become a pan-European indicator for SFM.

One of the most important measures to safeguard forest biodiversity is thus the protection of remaining old-growth and virgin forests (a *land sparing concept*). Old-growth stands can be managed or unmanaged, but are generally defined as stands with more than 200 years' growth (Peterken, 1996). Virgin forests which have never been significantly influenced by people constitute only 2% of European forests, with the highest proportion in Central-East and South-East Europe (Forest Europe, 2015). Such old-growth and virgin forests are biodiversity hotspots which also provide large long-term carbon storage (Luyssaert *et al.*, 2008). Much of the last remaining natural forests of Europe are located in Romania, but are increasingly being lost (Knorn *et al.*, 2012). In Finland also, the area of forest stands over 160 years of age has decreased by 23.4% during the past 15 years (Kotiaho, 2017).

A second means of enhancing biodiversity is to increase spatial structural elements in managed forests (a *land sharing concept*). Here, the deadwood and habitat trees are critical structural elements; for example, in Finland and many other countries about 25% of all forest species are either directly or indirectly dependent on deadwood (Siitonen, 2001; Paillet *et al.*, 2010). In the UK, approximately 20% of forest-dwelling species depend on dead or decaying wood for all or part of their life cycle (Humphrey and Bailey, 2012). Some countries apply specific forest certification schemes (FSC, PEFC) to improve biodiversity conservation in production forests. However, such measures, while avoiding complete loss of features important for biodiversity, can only moderate the harmful impacts of forestry on biodiversity and not enhance biodiversity. Certification is not therefore sufficient to significantly improve the conservation status in managed forests.

As managed forests cover large areas in Europe, protecting forest biodiversity requires the conflicts between timber production and biodiversity conservation to be addressed using alternative silvicultural methods such as retention forestry, where the unlogged part of the original stand maintains the continuity of structural and compositional diversity (Gustafsson *et al.*, 2012). Several authors emphasise that special forest structural elements, such as hollow trees, large trees, standing and lying dead trees should be maintained in managed landscape as well (Bauhus *et al.*, 2009; Brunet *et al.*, 2010). The maintenance of forest continuity is critical at stand and landscape scales for the protection of many forest-dwelling species, as their ability to disperse is limited in current fragmented landscapes (see, for example, Nordén *et al.* 2013; Abrego *et al.*, 2015). There are large forest areas in Europe that possess continuity in that they have never been converted to agriculture, and thus have undisturbed soils which can ensure the long-term survival of ancient forest species, and may also serve as sources for dispersal into the surrounding landscape (Hermy and Verheyen, 2007). Ensuring the continuity of forest stands at local and/or landscape scale is an important component of biodiversity protection.

The concept of land sharing versus land sparing originates from the question of how to combine food production and conservation (Green *et al.*, 2005; Phalan *et al.*, 2011; Tscharntke *et al.*, 2012), but can also be applied to the forestry sector (Cote *et al.*, 2010), although it is still under debate (Fischer *et al.*, 2014). With forests, land sharing is centred around integrating biodiversity conservation, and wood and fibre production on the same land. In Europe, it would require management strategies that maintain and/or restore natural levels of biodiversity while simultaneously satisfying the demand for wood and fibre. At the other end of the spectrum, land sparing separates land for wood and fibre production from land for conservation. By using selected species, fertilisation and/or irrigation, high production levels are realised in the managed lands, so that not all forest land available is required to supply the demand for wood and fibre—thus enabling protection of the remaining forest. Because the protected land has no other functions, rewilding some of Europe's forests could even be considered (Navarro and Pereira, 2012). Given that production partly depends on biodiversity (Liang *et al.* 2016), both approaches require careful design and implementation to be effective (Tscharntke *et al.*, 2012; Fischer *et al.*, 2014).

At present, intensive forest management and timber extraction produces little deadwood and often removes even the cutting residues, so that levels of deadwood in managed forests are relatively low at 4–7 $m^3$ per hectare. In contrast, in virgin and old-growth forests, the volume ranges from approximately 50 $m^3$ per hectare to more than 200 $m^3$ per hectare (Siitonen, 2001; Christensen *et al.*, 2005; Vandekerkhove *et al.*, 2009). This substantial reduction in the dead wood available for forest-dwelling species has had, and continues to have, a drastic negative effect on biodiversity. As mentioned above, the amount of deadwood in managed forests is one indicator of a forest's contribution to biodiversity, and allowing the percentage of deadwood to increase to 30% of natural levels (that is, approximately 15–60 $m^3$ of dead wood per hectare) could help to limit further biodiversity loss (Müller and Bütler, 2010; Hanski, 2011, 2013). Natural disturbances such as forest fires and windthrows can increase the amount of deadwood in both managed and old-growth forests. However, they are currently relatively rare events, and in managed forests their positive influence (from the biodiversity viewpoint) is often negated by removing the deadwood; consequently, they are of only minor importance for the majority of biodiversity at the European scale.

It should also be noted that factors contributing to biodiversity also coincide with those underpinning other aspects of sustainable forestry and associated ecosystem services. For instance, removing deadwood, branches, twigs, etc. also removes a source of soil humus and nutrients, while more frequent interventions (for wood extraction) also contribute to destruction of forest soil cover, increasing the risk of soil erosion—especially in hilly and mountainous parts of the EU. Gobin *et al.* (2011) provide several scenarios for residues removal from forests for bioenergy production and show that removal of 70% of wood residues and 25% of stumps leads to a serious decline in carbon fluxes and associated humus into the soil—especially pronounced in coniferous forests.

### 3.3 Protecting biodiversity

From the above discussion, it can be seen why old-growth forests are biodiversity hotspots, but also that managed forests play an important role. Biodiversity can thus be enhanced by (1) setting aside and protecting old-growth areas, (2) increasing deadwood and other structural elements in managed forests and (3) avoiding negative ecological impacts of management by including biodiversity in multi-functional forest management policies. The large differences in ecological and climatic conditions between eucalyptus plantations in Southwest Europe, poplar plantations in Eastern Europe, beech forests in Central Europe and boreal coniferous forests in the north require targeted measures, through both governmental and non-government processes, for protecting and increasing the biodiversity values in each region.

As already pointed out in section 2.1, diversity is important not just at the species level, but at the genetic level also. Genetic variations within species serve as a buffer against fluctuations of the environment (Larsen, 1995), and the many species in a biodiverse ecosystem provide genetic variation which contributes to the adaptability and resilience of ecosystems (Fares *et al.*, 2015). This relationship can be shown as a hierarchy (Figure 3.1) where threats such as habitat loss and climate change show their impacts at the ecosystem level, while the response of species in the ecosystem will ultimately be determined by their genetic architecture. Legislation such as the Habitats Directive focuses on the protection of particular animal and plant species rather than genetic diversity. Moreover, it focuses on the protection of breeding sites and migration resting areas of individuals rather than on the maintenance of viable populations at larger spatial scales, hindering the development of cost-effective and scientifically-based comprehensive conservation strategies (Jokinen *et al.*, 2015).

An important aspect of the assessment and monitoring of biological diversity is the use of existing and emerging genetic analysis technologies. The integration of molecular approaches and techniques can give additional and/or novel insights into the genetic diversity and structure of target species for genetic conservation efforts. Existing efforts[12] need to be integrated into long-term strategies to identify the genetic diversity of target species, as well as providing a platform for the assessment and monitoring of conservation efforts. In addition, molecular analyses can provide indicators for assessing and monitoring biological diversity, for example by the assessment of soil microbial diversity, and the correlation with other ecological parameters, including ecosystem services such as nutrient cycling, carbon storage and turnover, water retention, soil structure regulation, resistance to pests and diseases, and regulation of above-ground diversity (Girlanda *et al.*, 2011). In addition, high-throughput DNA sequencing strategies can be used for analysis of complex environmental samples to assess functional and ecological biodiversity as well as for identification of rare and endangered species (Shokralla *et al.*, 2012). These approaches can give a quantitative measurement of the efficacy of various conservation measures, and assessment of different silvicultural approaches and management regimes. A long-term and stable policy commitment would allow such methods to be integrated into existing conservation and monitoring strategies.

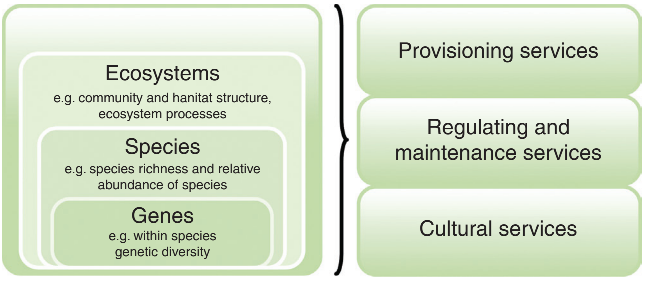

*Figure 3.1 Levels of diversity- from genes to ecosystems, and their role as supporting other ecosystem services.*

International efforts to safeguard biodiversity and ecosystem services are pursued under the CBD, which adopted Aichi target 11; according to which the world's areas of particular importance for biodiversity and ecosystem services should be expanded by 2020 to at least 17% of the terrestrial world. Biodiversity is not evenly or randomly distributed at global, continental or local levels (Myers *et al.*, 2000; Hillebrand, 2004; Brooks *et al.*, 2006). Global and continental scale analyses of the priority areas for biodiversity are needed to inform country level implementation of land use decisions both for development and for biodiversity conservation (Pouzols *et al.*, 2014; Di Minin *et al.*, 2016). There is compelling evidence that exclusively national conservation planning will result in ineffective conservation outcomes and wasteful use of financial resources due to uncoordinated actions between countries. As an example, let us consider the Aichi Target above. The present global protection area network covers 19% of the ranges of nearly 25,000 species of terrestrial vertebrates. A globally planned and implemented expansion of the terrestrial protected area network to the 17% target would **triple** the number of protected ranges of terrestrial vertebrates to 61% (Pouzols *et al.*, 2014). In contrast, exclusively nationally planned expansion of protected area networks would cover only 38% of the number of species ranges. To achieve the same level of species protection, a nationally designed network would have to protect 32% of the land surface—almost double that required for a globally designed network. The same principles apply to European biodiversity conservation, and a cost-effective pan-European protected area network should be based on a European-scale analysis of the priority areas for protection, which could then guide the implementation and expansion of protected areas in individual Member States.

Such a pan-European genetic conservation strategy was devised by the European Forest Genetic Resources Programme (EUFORGEN; De Vries *et al.*, 2012), taking into account the area of suitable habitat, the condition or the quality of the habitat and the spatial distribution of habitat patches (Hanski, 2005, 2011; Rybicki and Hanski, 2013). This would address the resilience and effectiveness of species protection by ensuring that spatial distributions of protected habitat patches are viable in the longer term. Such strategies

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[12] For example, FORGER (www.fp7-forger.eu) and LIFEGENMON (http://www.lifegenmon.si/).

need to recognise that conservation of biodiversity is very much a land use question, and the protection of large continuous areas (*land sparing*) is challenging to establish in places that have already been converted to human use. For this reason, a combination of *land sparing and sharing* is a more realistic and potentially effective approach. Aggregating new conservation efforts in multi-use landscapes that would cover half of the landscape, within which about 30% of the area would be set aside (spared) and the remaining two-thirds shared, offers one possible effective approach (Hanski, 2011; Rybicki and Hanski, 2013; Kotiaho, 2017).

A review of the EU biodiversity policy in the context of climate change (van Teeffelen *et al.*, 2014) also identified several important policy gaps that this EASAC report confirms: (1) conservation targets should be designed such that they better match conservation needs; (2) targets need to be set in a spatially coherent manner across national scales; and (3) current monitoring tools for biodiversity conservation and ecosystem restoration seem to be insufficient to address these gaps.

## 3.4 Measuring progress in meeting biodiversity targets

Improving biodiversity also involves commitments to recovering degraded land under recent global conventions. For example, in 2010 the international community, including the EU, adopted a target to restore 15% of degraded ecosystems by 2020 (CBD Target 15), and in October 2015, the UN General Assembly set a new goal to reach a land degradation-neutral world by 2030[13].

Setting quantitative targets for the restoration or cessation of land degradation generates a need for a means of measuring progress. The key is not just to be able to measure the area degraded but also to establish the magnitude of degradation within each area (Kotiaho and Moilanen, 2015). This will be very different for an ecosystem that has been only slightly degraded compared with one that has been almost completely lost. There is thus a need for a common point of comparison: that is, a baseline that is based on scientific assessments, against which measurements can be compared to show how much degradation has been caused and how much restoration has been achieved.

With a globally agreed quantitative restoration target, a baseline is needed that ensures fairness and comparability when assessing the magnitude of degradation and the success of restoration among countries that are in different stages of economic development (UNEP, 2003). An ecosystems pre-degradation state, also known as its natural state, provides such a baseline (Kotiaho *et al.*, 2016). This state has no human-caused loss of biodiversity or of ecosystem functions. The natural state baseline is independent of societal values and the time of development, making it fair and comparable across different countries.

If a baseline were to be adopted from some recent past, developed countries that transformed their environment centuries ago from its original natural state will appear to have degraded their land less than developing countries that have degraded their environment more recently. With such a baseline, the 15% restoration target for developed countries unfairly becomes less demanding than for developing countries. This inequity is corrected when the natural state is used as a baseline for measuring the magnitude of degradation.

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[13] http://www.unccd.int/en/programmes/RioConventions/RioPlus20/Pages/Land-DegradationNeutralWorld.aspx

# 4 Forestry in EU climate and energy policy

In considering the interaction between forestry and climate, there is a fundamental trade-off between using forests for carbon storage, and harvesting the wood. In some uses of wood (e.g. construction materials[14]), carbon continues to be stored for long periods, but in others (particularly biomass energy) the carbon contained in the wood is released to the atmosphere almost immediately. Harvesting immediately reduces the standing forest carbon stock compared with less (or no) harvesting (Bellassen and Luyssaert, 2014; Sievänen *et al.*, 2014) and it may take from decades to centuries until regrowth restores carbon stocks to their former level—especially if old-growth forests are harvested.

When forest biomass is used to substitute for fossil fuels, it should also be noted that harvesting and processing of that biomass requires fuel inputs. Moreover, the combustion of forest biomass for power generation or heating will generally release more carbon dioxide to the atmosphere per unit of delivered electricity or heat than fossil fuels, owing to biomass having lower energy density and conversion efficiency (Ståhls *et al.*, 2011; JRC, 2013; Smyth *et al.*, 2016a; Soimakallio *et al.*, 2016). The overall climate effects of using wood for energy thus depend on the life cycle GHG emissions of the sources of the wood (short rotation coppice, harvesting residues or roundwood) and are highly case-specific.

Policies for the use of forest bioenergy need to take into account not only natural sciences but also social sciences because the physical aspects of wood production and the economic profitability of forestry must be integrated with other policy and economic objectives such as ensuring security of energy supplies, rural job creation, limiting carbon emissions, returns on investments as well as competitiveness in energy markets. Short-, medium- and long-term life-cycle analyses are needed to assess the costs, benefits and trade-offs of policy instruments and incentive structures for bioenergy. These must address the full range of climate impacts and other externalities in markets for forest biomass, which may take more than 100 years to grow and may then have lifetimes of a further 100 years or more. As already mentioned in section 1.2, applying the cascading principle and prioritising applications that store the carbon contained in the wood for long periods (e.g. construction) can delay the emission of its carbon content into the atmosphere. However, even when applying the cascade principle, because forest resources include low-grade biomass and other by-products (e.g. black liquor) that are suitable only for incineration, some carbon may be returned to the atmosphere in the short term. This chapter explores some of these issues and their implications.

## 4.1 Forest bioenergy and EU climate policy

### *4.1.1 On carbon neutrality*

The use of biomass for energy is often linked to the concept of *carbon neutrality* (see review in Johnson, 2009). According to this concept, harvesting of forests and using wood for various purposes such as bioenergy may release carbon dioxide quickly after harvest, but these emissions are re-absorbed by the regrowth of the harvested stand over time, or by growth in other stands on a landscape scale which act as carbon sinks, thus compensating for the initial emissions[15]. On this simple model, forest biomass can be said to be carbon neutral because a mechanism exists for emitted carbon to be reabsorbed. The carbon neutrality argument has given a strong boost to policies that aim to increase the use of forests as a source of bioenergy and as a substitute for fossil energy, with forest biomass being classified as renewable, and currently contributing substantially to the EU's renewable energy targets (section 1.2.2).

The validity of the carbon neutrality concept has been intensively studied and has been shown to be highly simplistic. The inherent lower energy density of biomass means that more has to be burnt (relative to fossil fuels) to generate the same amount of electricity or heat; thus initial emissions are higher. Moreover, the length of time needed for those emissions to be compensated by the growth of new forests, called the carbon *payback time* (see below), can be substantial (Fargione *et al.*, 2008). Unsustainable utilisation of forests (for example leading to land use change, or conversion of old-growth forests to intensively managed, shorter rotation forests) unavoidably decreases carbon storage in living trees and forest soils. With SFM, the net effect of harvesting on GHG emissions depends critically on how the harvested timber is utilised. Using wood in durable commodities and construction stores carbon over long periods, while energy production causes immediate carbon release.

The concept of carbon neutrality must therefore be considered on a case-by-case basis together with the

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[14] Materials such as steel and concrete have high GHG footprints which can be avoided by substitution (Schlamadinger *et al.*, 1996; Pingoud *et al.*, 2010; Sathre and O'Connor, 2010).

[15] This concept starts with the harvest and has led to the term 'carbon debt' to describe the carbon that needs to be 'repaid' through future growth. But an alternative model would see the carbon released as using a carbon credit from the past that is cashed in through its use (Pelkonen *et al.*, 2014). Discussion must thus make it clear the reference time being used.

related payback period. Long payback periods mean that use of forest bioenergy may jeopardise short- (less than 10 years) and medium-term (10–50 years) emission reduction objectives even if longer-term ‘carbon neutrality’ can be achieved (Bellassen and Luyssaert, 2014; Sievänen *et al.*, 2014). Fundamental to the net carbon balance effects of forest-based biomass energy is the *type of forest biomass* utilised. Where the biomass would decompose fast if not utilised (for example, in the case of some harvest residues), there could be an overall beneficial climate effect if that biomass were used to produce energy in place of fossil fuels (although with a negative effect on biodiversity; Toivanen *et al.*, 2012). In countries with long traditions of forest industry, much of the wood-based energy is currently produced from residual or waste materials from the forest industry (for example black liquor) with such beneficial climate effects.

However, if trees with a large ongoing carbon storage potential are harvested, then the emissions from burning the biomass would be associated with the loss of a carbon sink, and the net effect on the climate is likely to be negative (Smyth *et al.*, 2016b; Soimakallio *et al.*, 2016). Further, harvesting reduces forest soil carbon levels (Nave *et al.*, 2010; Achat *et al.*, 2015), and studies in which these losses are accounted for have shown that the use of forest biomass for energy production may yield up to 40% higher carbon dioxide emissions than fossil fuel (Mäkipää *et al.*, 2015; Bradford *et al.*, 2016; see Matthews *et al.* (2014) for a review). The recent expansion of the use of biomass in many countries has extended the range of biomass feedstocks to include roundwood, from which the climate impacts depend very much on the growth rate of the tree species in question. Slow-growing trees have long payback times and JRC (2013) notes that ‘*in the case of stemwood harvested for bioenergy purposes only, if all the carbon pools and their development with time are considered in both the bioenergy and the reference fossil scenario, there is an actual increase in $CO_2$ emissions compared to fossil fuels in the short-term (few decades)*’.

In short, utilising forests for bioenergy combines many factors that vary over time and from case to case, so it is too variable to be labelled simply as carbon neutral (Schulze *et al.*, 2012). The label of carbon neutrality obscures the reality that carbon management does not offer any general context-independent justification to increase forest utilisation. Additionally, it hides the significant possibilities to promote the use of forest ecosystems as carbon sinks, which should be considered an essential component of climate change mitigation through forest management.

### 4.1.2 Comparing forest biomass energy with other energy sources; life cycle assessment

Under the EU’s non-binding recommendations for Member State rules on sustainability of solid biomass[16], biomass should deliver a minimum level of GHG ‘savings’ over their life cycle (cultivation, processing, transport, etc.) compared with fossil fuels, and such standards are already applied or exceeded in some Member States. This may give the impression that switching from fossil fuels to biomass reduces emissions; however, this would be misleading and an objective comparison of emissions is complex and the source of considerable controversy[17]. We attempt to summarise some of the key factors in this section.

The current method for measuring GHG ‘savings’ is to compare the emissions from burning fossil fuels with the emissions from cultivating, processing and transporting a quantity of biomass with similar energy-producing content. This calculation does not include the release of (biogenic) carbon contained in the biomass on combustion (see next section), nor the secondary effects on the carbon stocks of the forest that has been harvested for biomass. In addition, the inherently lower energy density and lower combustion efficiency of biomass lead to carbon dioxide emissions per unit of energy produced being 1.2, 1.5 or 2 times higher than when using coal, diesel oil or natural gas, respectively (IPCC, 2006). This means that, as already noted, switching from fossil fuels to forest biomass to produce the same amount of energy, inevitably increases carbon dioxide emissions.

In the previous section, we introduced the carbon payback concept to refer to the time needed to reabsorb the amount of carbon dioxide released by the combustion of the harvested biomass. However, in reality, the biomass harvested for bioenergy purposes would have continued to grow and absorb carbon dioxide for at least some time. Moreover, other scenarios are possible—for instance, a previous semi-natural forest could be converted post-harvest to plantation forest, or agriculture. The net climate effects of harvesting a forested area for bioenergy will thus be a combination of the emissions from burning and the loss of carbon absorption potential after harvest. This means that even after the carbon payback period has passed, there may still be a lower carbon stock than if the biomass had not been harvested, and additional

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[16] The recommendations in COM (2010)1 apply to energy installations of at least 1 megawatt thermal heat or electrical power, and forbid the use of biomass from land converted from forest, and other high carbon stock areas, as well as highly biodiverse areas. They require that biofuels emit at least 35% less GHG over their lifecycle (cultivation, processing, transport, etc.) compared with fossil fuels. For new installations, this amount rises to 50% in 2017 and 60% in 2018.

[17] As illustrated by the conflict as we went to press between Chatham House and IEA Bioenergy (https://www.chathamhouse.org/sites/files/chathamhouse/publications/research/2017-02-23-woody-biomass-global-climate-brack-final2.pdf) and IEABioenergy (http://www.ieabioenergy.com/publications/iea-bioenergy-response/).

time will be needed to reabsorb sufficient carbon to compensate for this loss and achieve 'carbon parity'. As can be seen in Figure 4.1, until the parity payback time is reached, atmospheric concentrations of carbon dioxide will be higher than if biomass had not been used to replace fossil fuels. Parity payback periods vary greatly, with cases where slow-growing trees would be harvested from boreal forest to replace fossil fuels extending to 100–300 years (see, for example, McKechnie *et al.*, 2011). These inherent uncertainties in the use of forest biomass have long been recognised (see, for example, EEA, 2011).

Three scenarios based on using different types of forest biomass are presented below to illustrate the potential policy implications of different payback periods[18].

Scenario 1. This reflects the historical practice in much of EU forest management, where bioenergy is part of the forest products chain and comes from residues, by-products of processes such as pulping (black liquor), and low-quality wood, sawing losses, post-consumer waste and such. In Scandinavia, for instance, whole villages are heated with residual heat from pulp mills or bioenergy units producing both electricity and heat from such residues. Available evidence indicates that these sources have parity payback periods of decades at most.

Scenario 2. The scenario of increasing extraction of forest biomass for bioenergy was recently analysed by Nabuurs *et al.* (2017). Eight forest types across Europe with contrasting growth and management characteristics were considered, and the time required to reach carbon parity calculated when increasing harvesting rates, rates of thinning or residue removal—while maintaining existing environmental and biodiversity rules (Nabuurs, 2006; Elbersen *et al.*, 2012; Verkerk *et al.*, 2014). They compared biomass with both coal and natural gas fossil fuel comparators, and found that the time to reach parity ranged from short (approximately10 years with increased use of forest residues), through decades to 100 years (increased rate of thinning), to about 100 to more than 500 years when felling was increased for the purpose of bioenergy and certain types of forest were involved (Figure 4.2).

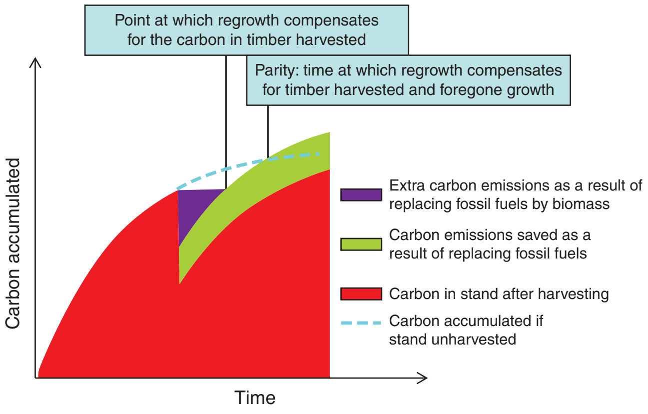

*Figure 4.1 Conceptual diagram of carbon debt and parity. Source: adapted from Nabuurs et al. (2017).*

Scenario 3. This is applicable in countries that use forestry biomass for electricity generation and/or heat generation in large-scale power plants. Mitchell *et al.* (2012) compared net GHG emissions under scenarios where natural forests and plantation forests were left to grow, relative to being clear-cut every few decades to provide fuel for power plants. They found carbon payback periods that ranged from 'centuries' (older natural forests) to 'decades to centuries' (plantation forests). Stephenson and Mackay (2014) considered a range of scenarios from using forestry by-products to felling whole trees to provide biomass for electricity generation. Some of their findings are summarised in Table 4.1, and show that pellets derived from sawmill residues or forest residues that would otherwise be burnt offer significant GHG savings over a 40-year period. However, where coarse residues (for example trunks and roots) or whole trees are taken, GHG savings only occur over 40–100 years (or longer).

The implications from a climate perspective of such huge ranges in potential impacts are thus substantial. While using sources of residual wood (for example residues, tree thinning) for energy can make a positive contribution to climate mitigation within a decade or so, expanding demand to include whole trees can swiftly move to scenarios that exacerbate climate change for centuries. In this context, a recent analysis by the European Forest Institute (Berndes *et al.*, 2016) recognises that the economic and environmental benefits of the use of forest biomass for energy are highly variable and require appropriate measures to promote best practices in forest management for climate change mitigation. The compatibility of these scientific conclusions with the current regulatory framework is considered below.

An emerging question is whether basing comparisons of wood-based bioenergy with emissions from fossil fuels is becoming outdated, because other renewable energy technologies (including solar and wind) that have very low GHG emissions are fast becoming cost-competitive and increasing their penetration into EU energy markets. It may thus be more appropriate from

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[18] It has been argued that carbon balances should not be assessed at the stand level since at landscape level depletion of carbon in one stand may be compensated by growth in a stand elsewhere. For scientific analysis of the impact on climate forcing, however, it is necessary to compare the effects of various bioenergy harvest options against a baseline of no bioenergy harvest (or other credible counterfactual scenarios) for the same area of forest. Such studies provide information on the impacts of changes at the stand level, which can then be integrated with other factors (economic, regulatory and social) that may influence effects at landscape level.

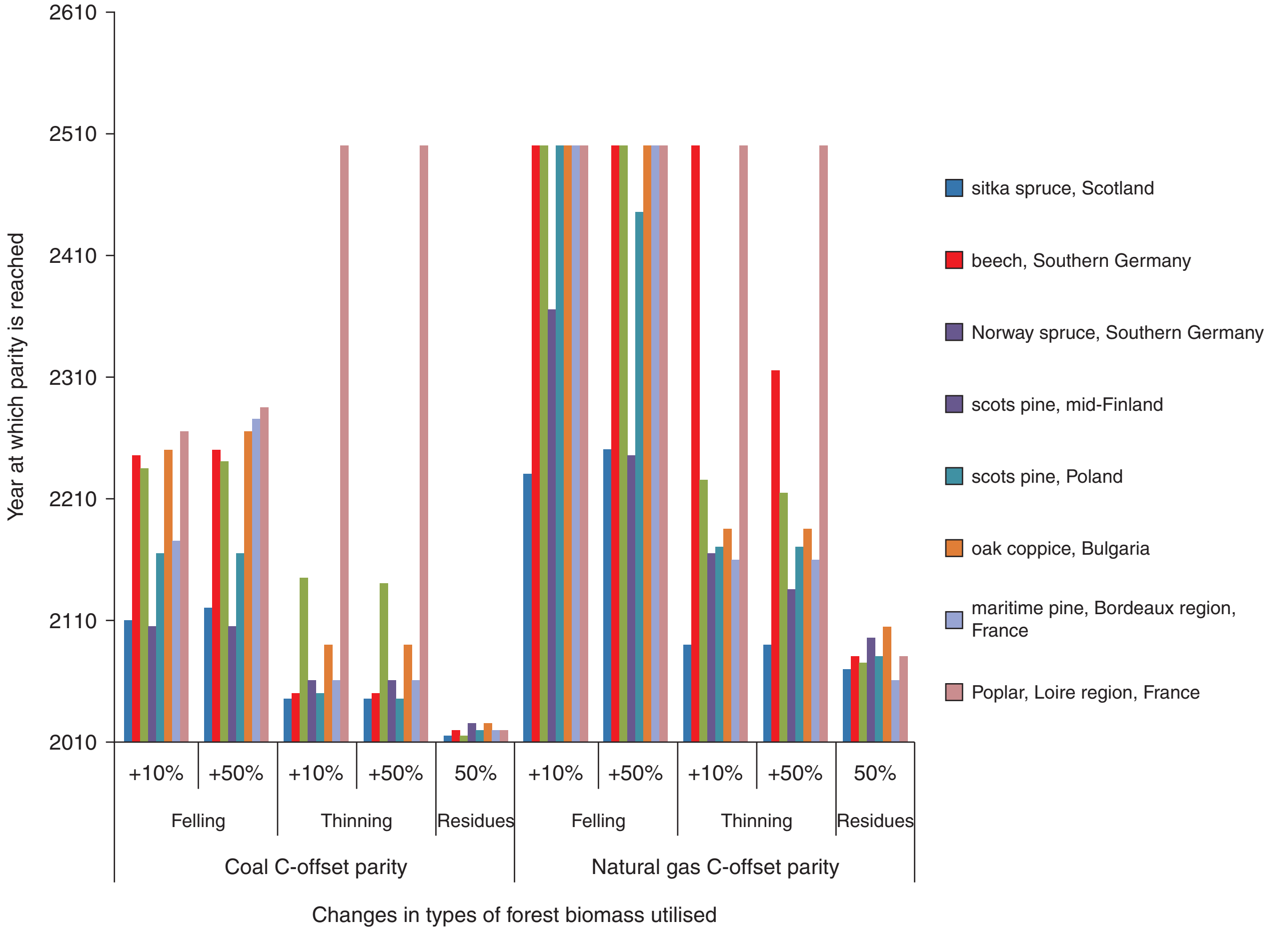

*Figure 4.2 Year of parity repayment for different rates of harvesting, thinning and residue removal against coal, gas for eight forest types in Europe (Nabuurs et al., 2017).*

***Table 4.1 GHG impacts of bioenergy scenarios (40 year); adapted from Stephenson and Mackay (2014)***

| | Greenhouse gas impacts in kgCO$_2$/MWh electricity (natural gas and coal reference values are 440 and 1000 kgCO$_2$/MWh respectively) | | |
|---|---|---|---|
| | <100 | 100–400 | >400 |
| Woody residues | Forest residues and sawmill residues that would otherwise be burnt as waste.<br>Trees killed from natural disturbances that would otherwise be burnt as waste. | Fine residues that would otherwise be left to decay.<br>Coarse residues that would otherwise be left to decay (for a southern US forest). | Coarse residues that would otherwise be left to decay in the boreal forest.<br>Trees killed from natural disturbances that would otherwise be left in a boreal forest. |
| Roundwood and energy crops | Increasing the yield of a plantation without increasing the rate of harvest.<br>Wood from the forest that would otherwise be converted to agricultural land.<br>Converting land that would otherwise revert to grassland into biomass plantations. | | Additional wood output from increasing the harvest rate of forests.<br>Wood from forests that would otherwise be harvested less frequently<br>Converting forests into energy crop plantations.<br>Converting land that would otherwise revert to forest into biomass plantations. |

a climate perspective to compare the climate impacts of bioenergy with those of other renewable energy technologies rather than with those of fossil fuels.

### 4.1.3 Forestry in the EU: GHG emission accounting principles and climate and energy policy

In the current EU climate policy framework, forests and forest bioenergy are included in the LULUCF sector that is not yet part of the EU's emission reduction target for 2013–2020. According to these accounting principles, Member States must report on changes in forest land areas, and any related decreases in carbon storage due to deforestation must be compensated by emission reductions elsewhere. Changes of carbon stocks in existing managed forests are compared with forest *reference levels* (anticipated carbon sink or the carbon sink at some base year).

Forest carbon sink or stock changes are measured by applying the 'instantaneous oxidation' principle, which assumes that carbon in harvested trees is instantaneously released to the atmosphere when harvested. Under this accounting principle, forest biomass used for bioenergy is assumed to have already released its carbon to the atmosphere and this is why, to avoid double accounting, its emissions are not accounted for when the wood is actually burnt. Because some fraction of carbon in harvested trees is in reality stored longer in wood-based products, Member States are required to observe changes in the pool of wood-based forest products as well.

In the accounting principles proposed in July 2016[19], carbon removals from the atmosphere above the forest reference level can be used partly to compensate for excessive emissions in other sectors. A critical feature in these latest proposals is thus how future forest reference levels for Member States will be specified. If the reference levels and sinks are lower (in absolute terms) than actual 'business as usual' levels, countries have the possibility to increase emissions from managed forests by increasing bioenergy production and decreasing carbon storage. To avoid creating an incentive towards such a perverse outcome, it is important that future reference levels should be set on an objective basis.

One effect of the 2009 RED and its resulting incentives has been that in some Member States substantial amounts of forest biomass have been imported (especially from USA and Canada) to produce electricity—either in dedicated biomass boilers or in co-firing with coal. This has allowed the importing country to report a reduced level of carbon dioxide emissions because emissions from biomass are not counted at the point of combustion. However, in reality such reported reductions do not equate with a contribution to climate change mitigation; rather, the importing country is taking advantage of the accounting rules and exporting responsibility for reporting emissions to the country that provided the feedstock and is thus responsible for LULUCF reporting.

The uncertainties and inconsistencies in assessing and regulating the use of solid biomass for energy have attracted much attention and led to the current EU non-binding sustainability criteria, while the European Commission has also reported on the use of biomass in Member States (EC, 2014). More recently (during 2016), the Commission has been consulting on post-2020 biomass sustainability criteria and has revised the criteria in its proposals for a new RED (EC, 2016a). The latter has taken into account an impact assessment that summarises the basic scientific issues and is in close agreement with the findings of this report, as shown in Box 6.

### 4.1.4 Alternatives to existing GHG emission accounting principles

According to general economic principles, emissions of harmful substances such as carbon dioxide are seen as 'negative externalities' (Stern, 2006), which are not taken into account by private actors in market economies, and thus require market interventions such as legal restrictions, taxation or emissions trading. In contrast, carbon storage in forests represents a 'positive externality' (a beneficial factor not recognised by the market and thus not priced), which should be promoted if it is to be taken into consideration by private actors in their decisions. As described above, current incentives feature prominently in using forest biomass for renewable energy, but forest-based carbon sequestration's potential contribution to negative emissions remains an opportunity yet to be realised (Ellison *et al.*, 2014).

The adjustment of economic incentives/disincentives to discourage emissions and encourage carbon sequestration can be characterised in the '*cleaner earns, polluter pays principle*'. This simple principle would suggest that carbon storage (i.e. negative emissions) should be subsidised and emissions from forest bioenergy should be accounted for and controlled

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[19] In July 2016, the European Commission launched a proposal for a regulation on the inclusion of GHG emissions and removals from LULUCF within the 2030 Climate and Energy Framework that aims at a total emission reduction of minus 40% by 2030 (COM 2016 479 final) in all sectors. In this new LULUCF proposal, removals from managed forest, minus a reference level, can be cumulated over the 10-year commitment period. The main target set is the 'no debit rule': that is, concerning LULUCF, a Member State has to perform as well as in the past and emissions from within this sector (from cropland, grassland, etc.) can be compensated for by sinks in the same LULUCF sector limited in total to 280 million tonnes. Further, there is very limited flexibility towards the Effort Sharing Regulation (ESR), which allows compensation of emissions in ESR sectors – transport, housing, waste and non-$CO_2$ agriculture – limited to a maximum annual 3.5% of Member State base year emissions (approximately 196 Mt $CO_2$/yr).

**Box 6 Scientific issues relevant to the use of forest biomass for energy in the European Commission's 'Clean Energy for all Europeans' package**

The Commission has previously (EC, 2014) noted that biomass is key to achieving the 2020 renewable energy targets and the EU long-term decarbonisation goals by 2050. The Commission also noted that, for the post-2020 period, an improved biomass policy would need to be developed '*in order to maximise the climate and resource efficiency benefits of biomass in the wider bioeconomy, while delivering robust and verifiable GHG emission savings and minimising the risks of unintended environmental impacts*'. More recently, the Commission published a package of proposals entitled 'Clean Energy for all Europeans' (EC, 2016a), which includes proposed revisions to the RED and the role of bioenergy. In its analysis, the Commission provides a summary of its assessment of solid biomass issues with which EASAC strongly concurs—specifically with the following (EC, 2016b):

- The Commission's recognition of the basic problems. Here, the first two problems are particularly relevant to this report (*1. The climate performance of bioenergy varies, and in particular biogenic $CO_2$ emissions associated with an increased demand for forest-based biomass may lead to minimal or even negative greenhouse gas savings compared with fossil fuels. 2. The production and use of biomass for energy can lead to adverse environmental impacts on biodiversity, soil and air quality.*)
- The Commission's recognition that '*The impacts on climate change of solid and gaseous biomass used for heat and electricity are complex and can vary significantly (from very positive to very negative impacts, i.e. reducing or increasing emissions compared to fossil fuels). However, a growing body of scientific evidence is available to understand these impacts.*'
- Confirmation that the primary objective of bioenergy is climate change mitigation.
- Full recognition of the importance of the timescale given the lengthy re-growing period for forest biomass.
- Recognition of the importance of biogenic emissions from pre-existing carbon pools.
- Recognition that as demand for bioenergy increases, there will be a shift from low-impact sources with a positive contribution to climate change mitigation (forestry by-products and residues, black liquor, low-quality roundwood, etc.), through sources with a more marginal contribution (for example small roundwood which competes with other uses, removing the carbon stock in stumps and other coarse residues), through to sources with a potentially exacerbating effect on climate change (for example felling whole trees for production of wood pellets).
- The Commission's recognition of the inherent weaknesses of the split in accounting, and comments that the zero rating for bioenergy emissions at the point of combustion has often been misinterpreted as meaning that biomass combustion is always carbon neutral.

through appropriate means, such as taxation, emission trading or legal restrictions (Tahvonen, 1995). Policies aiming to motivate owners to increase the carbon storage in their forests exist. For instance, in New Zealand, forest owners are compensated according to carbon stored, and in Ontario (Canada), forest owners with higher than a benchmark carbon sequestration can earn carbon credits to be sold in emission trading (Asante and Armstrong, 2016). Models thus exist for payments for such ecosystem services. It is, however, unclear whether the present accounting framework (with its IPCC origin) can provide the basis for an economically efficient scheme for controlling these externalities by means of incentives.

## 4.2 Bioenergy production with fast-growing coppices

One option for producing forest bioenergy is to use short rotation coppicing (SRC) as the source of biomass fuel. Decades-long research has led to solid SRC expertise in several countries, with practical experience of growing poplar and willow at high densities, and this has been translated into best practice guidelines[20]. Yet, the environmental impacts and economic viability of SRC as an alternative energy source to fossil fuels are still under debate, and a widely accepted methodological approach for performing the required life cycle assessment is lacking. For example, the net GHG budget of different management approaches depends on the amount of energy used (for instance in irrigation, pesticides), and on the emissions of non-carbon-dioxide GHG such as methane and nitrous oxide, which are influenced by land-use changes and fertiliser use. These last two gases have global warming potentials that are substantially greater than those of carbon dioxide[21].

Despite such uncertainties, recent reviews suggest that carbon emissions per unit of energy produced by SRC (electricity or heat) are substantially below those associated with fossil fuels (Njakou Djomo *et al.*, 2013, 2015). The rapid rotation also makes the carbon payback time relatively short.

There are also suggestions that SRC could be a multi-purpose, multi-functional source of woody crop production. SRC has in practice sometimes been accompanied by the establishment of other coppice plantations for energy purposes that, through an increase in forest areas and improved forest management, can also increase forest carbon stocks (Miner *et al.*, 2014). However, studies have shown that bioenergy from SRC is not yet economically viable across all European countries (El Kasmioui and Ceulemans, 2013).[22]

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[20] For example, http://www.seai.ie/Renewables/Bioenergy/Willow_Best_Practice_Guide_2010.pdf; http://www.forestry.gov.uk/fr/infd-8a5kl3

[21] The global warming potential of methane ranges from 34 to over 100 depending on the time frame; while that of nitrous oxide is 268–298 (IPCC, 2013).

[22] An approach to mitigation of climate warming via negative emission technologies using bio-energy with carbon capture and storage (BECCS) has been proposed. However, all negative emission technologies lack proper evaluation of economic feasibility and true climate impacts (e.g. the land use intensity and water requirements of BECCS are quite high) (Smith *et al.*, 2015).

### 4.3 Conflicts in land use for bioenergy production

The above analyses show that there are potential trade-offs and conflicts between forest harvesting policies, climate change mitigation and biodiversity. Some of the key potential conflicts include old-growth versus shorter rotation periods; residual biomass clearance versus dead and decaying wood as a source of biodiversity and soil fertility; and land use conflicts (reviewed in Felton *et al.*, 2016). Such inherent conflicts mean that conventions and treaties in different sectors may contradict each other. For example, in 2009 the EU's RED set a binding target of 20% of final energy consumption from renewable sources by 2020, and this has since been raised to 27% by 2030. Simultaneously, the CBD stated that by 2020, the terrestrial protected area networks should be increased to 17% and that 15% of degraded lands should be restored (Chapter 3). It is necessary to consider how far these separate objectives are compatible with each other.

To produce biomass for energy requires more land than most other energy sources (Brook and Bradshaw, 2014), and therefore raises a potential conflict by limiting the land area that is available for biodiversity conservation (Wise *et al.*, 2009; Foley *et al.*, 2011). For instance, the favourable GHG reductions offered by SRC (or equivalent energy crops including *Miscanthus*) relative to forest bioenergy sources may lead to an increased demand for land, which in turn may also compete with areas valuable for biodiversity. Indeed, Santangeli *et al.* (2015) combined data on the global distribution of the most biodiverse areas with global data on land-based renewable energy production potential (including bioenergy from dedicated plantations for *Miscanthus*) and found a considerable overlap between areas with bioenergy production potential and top biodiversity areas (approximately 40% of the bioenergy production potential in Europe is situated in the top 30% of the most biodiverse areas).

As a result, Kareksela *et al.* (2013) argue that, when assigning priority for land use, the potential for renewable energy production should be assessed in comparison with the needs of biodiversity protection or land restoration. In this context, biodiversity in SRC is higher than in agriculture[23] but less than in some areas (such as grasslands) that it could replace. Informed by an EU-wide analysis of such trade-offs, Member States would be able to target renewable energy production locally in areas that would least harm biodiversity. The commonly cited option of growing SRC on degraded (sometimes called marginal) land may not be an economically viable solution owing to the increased costs and lower yields.

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[23] For example, the reduced disturbance in SRC allows for perennial plant species, potentially providing a stable refuge and food sources for various invertebrates (see Rowe *et al*., 2011), for breeding birds of shrubs and hedges (see Londo *et al*., 2005) and for gamebirds (see Baxter *et al*., 1996). Creating habitat heterogeneity by maintaining a diversity of plantation ages and biomass crops also enhances the diversity of small mammal species across landscapes (Moser *et al*., 2002).

# 5 Opportunities for optimising forest management towards multiple objectives: wood production, climate change and biodiversity

Society's expectations of the benefits to be received from forests have expanded in recent years from the historical provisioning services (timber, pulp, etc.) to others which include contributing to climate change mitigation and biodiversity protection. A key challenge is to ensure that current scientific evidence on forests' multi-functional role can be applied in forest policy and silvicultural management, and better account for the potential trade-offs between various social, economic and ecological contributions. Developing improved forest management alternatives requires sharing new knowledge between forest experts, the forest industry and various interest groups. Here we consider some of the conclusions of our assessment of the current science with direct implications for management in different parts of Europe, and include examples of national policies for each of the main forest types.

## 5.1 Boreal forests

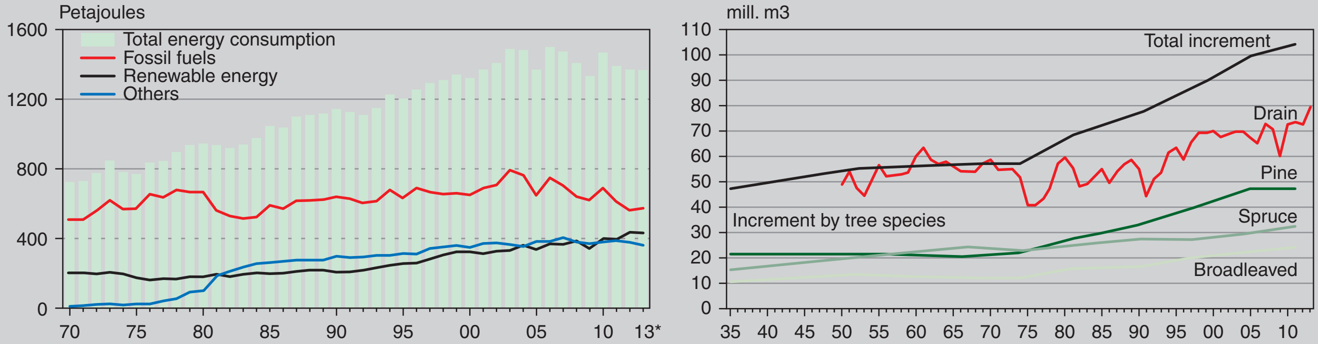
Currently, Northern European (Fennoscandia and Baltic countries) forests are widely managed for wood production using intensive silvicultural management practices such as clear-cuts followed by planting or other artificial regeneration methods (Kuuluvainen, 2009). Earlier and to some extent even nowadays, the primary objective was to reach maximum sustainable yield for timber production. This objective is, however, too narrow even from the point of view of timber production and should be extended to include prices, costs, interest rate and forest owners' financial and other objectives (Samuelson, 1976). Taking these broader objectives into account may lead to changes in the choice of tree species, planting density and timing of harvesting activities in sustainable and economically viable forestry (see, for example, Kuuluvainen *et al.*, 2012; Tahvonen *et al.*, 2013). Such observations have recently led (for example in Finland) to diversified forest management recommendations that differ from the traditional volume maximisation of timber production, and that receive strong support from both the public (Li *et al.*, 2004) and forest owners with varying objectives. Moreover, such diversification helps to balance the multiple objectives in forestry, such as recreation, biodiversity conservation and climate change mitigation.

From the carbon management perspective, the management of Northern European forests may need to change to properly integrate both wood production and carbon sequestration. Given an adequate economic price for carbon emissions, including this in the economics of forest management would imply major change. It would become economically rational to increase planting density, to postpone intermediate harvests (thinning) and to apply longer rotation periods, relative to forestry focused on previous timber production objectives (Van Kooten *et al.*, 1995; Pihlainen *et al.*, 2014). In the case of a price for carbon of approximately $50 per tonne of carbon dioxide, it would become economic to increase the carbon stored in forests by up to 40% and, in the long run, the market supply of wood would increase as a consequence of increased forest stocks. Importantly, the costs of optimising storage of carbon through changes in forest management would be considerably lower than alternative climate change mitigation methods, thus offering a lower potential cost to achieving climate targets (Pihlainen *et al.*, 2014). Further, those management choices that lead to increases in albedo and to forest coverage that produces more climate-cooling aerosols can be considered generally climate-friendly. This wide range of management options presents a challenge for the LULUCF policy to provide appropriate incentives for changes in forest management. Two examples of approaches to the multiple objectives of boreal forestry are given in Box 7.

Although forest biodiversity does not have an explicit economic price, recognition of the trade-offs could also include biodiversity protection through forest management in Northern regions. Forest biodiversity is dependent on decaying wood that is almost absent in boreal artificially regenerated forests. To increase its quantity, one measure is to shift from single-species forests towards more heterogeneous, mixed-species forests where some trees are left to decay without harvesting. Other positive outcomes from mixed-species forests include higher aesthetic and recreational values, as well as reduced stand vulnerability to forest fire, pest and pathogen damage. Additionally, the risks, uncertainties and increasingly observed damage caused by climate change may favour an increase in heterogeneous mixed-species forests, as they provide forest managers with wider options for coping with future situations (Gauthier *et al.*, 2015). For instance, thinning and selection cutting aimed at increasing species diversity may be used to support more drought-resistant species and reduce the risk of fire and insect infestations. Transforming some fraction of single-species stands into mixed stands, would offer a promising risk-averse strategy and lead to greater vitality and resistance against abiotic and biotic disturbances. Such approaches are supported by recent research

## Box 7 Boreal forest policies (multi-functionality)

The economic role of forestry is large in **Finland** (the forest industry is responsible for about 20% of exports). In spite of intensive forest utilisation, forest resources in Finland have been continuously increasing over the past half a century. The use of wood-based energy has been increasing and accounted for approximately 35% of total energy consumption in 2013 and using around half of the annual wood consumption (mainly from forest industry by-products). Bioenergy is the main component of Finland's renewable energy which constitutes 32% of total energy consumption (see left panel on figure below).



*Left: Total energy consumption by form of energy, 1970–2013. Right: annual increment of growing stock and drain 1935–2013. (Sources: Statistics Finland, Finnish Forest Research Institute/LUKE.)*

In November 2016, the Finnish Government announced its ambitious new climate and energy plan for 2030, which aims to increase the role of forests in both energy production and climate change mitigation. It includes the goal of abandoning the use of coal for energy by 2030, and achieving a carbon-neutral energy system by 2050. The use of forest biomass for advanced transport fuels will be increased through biorefining (bioliquids and biogas); financial incentives (subsidies) will encourage using forest chips and forest industry by-products for combined heat and power, and for heating. An operating subsidy scheme for electricity produced from wood chips will continue at least until 2018.

The plan has major consequences for Finnish forest carbon storage and biodiversity values. It implies an intensification of historical forest use (see right panel on figure above) by increasing harvests from the current 60 million $m^3$ to approximately 80 million $m^3$ annually, to reach more than 50% of renewable energy by the 2020s. This will significantly reduce the forest carbon sink in the near future to 13.5–20 from the current 22–50 million tonnes carbon dioxide per year (http://tietokayttoon.fi/en/article/-/asset_publisher/10616/selvitys-hallitusohjelman-energia-ja-ilmastotavoitteet-saavutettavissa). The decline of carbon sinks resulting from increased biomass use is suggested to be offset by fortifying the growth and carbon-binding capacity of forests in the long run, by mapping out the afforestation of treeless areas and reducing the clear-cutting of forests in connection with infrastructure and transport construction. However, the viability of these measures has been questioned by forest experts (http://www.bios.fi/publicstatement/publicstatement240317.pdf). The impacts of increased harvests to forest biodiversity are foreseen to be large, and will critically depend on effective biodiversity conservation measures. Finland has a system that allows payment for ecosystem services for protecting biodiversity and other non-use values of forests, albeit the budget for this purpose is small.

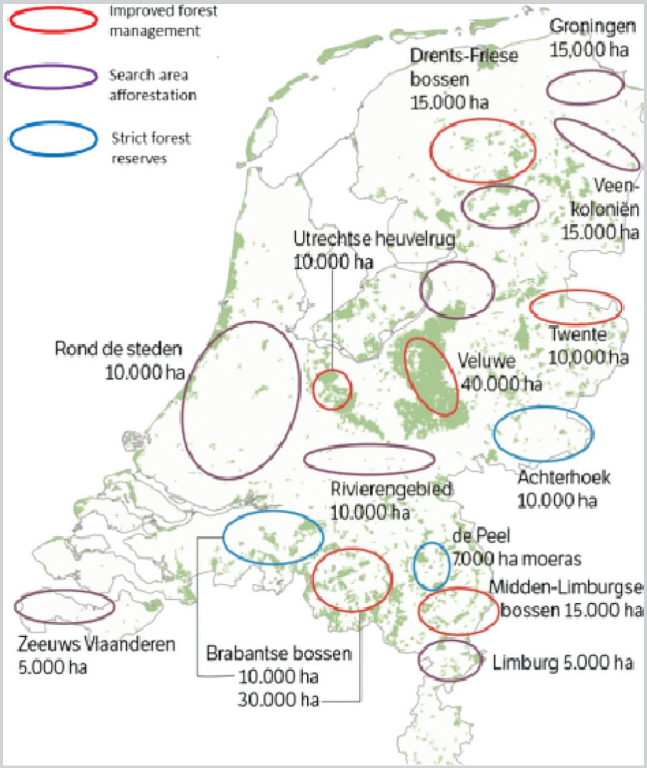
Also in the boreal biogeographical zone, **Estonia**'s forestry development plan was adopted in 2011, in which the productivity and vitality of forests and their multiple and efficient use was cited as the main goal. The plan has specific targets including protection of habitats and natural environment, diversifying recreation options, and supporting through R&D and other measures the competitiveness and adaptability of forest sector enterprises. The intensity of Estonian forest management ranks between Scandinavia and Central Europe—with a moderate intensity based on strong silvicultural practice. Annual removals have increased recently to 90% of the annual net increment, and therefore raise concerns about maintaining biodiversity and habitats. To balance economic and technological functions, 10.4% of forest area is strictly protected and restrictions are applied to an additional 14.7%. Debate continues on other measures including increasing the harvesting age in commercial forests and strengthening strictly protected areas.

which shows a positive correlation between biodiversity and forest productivity (Liang *et al.*, 2016).

However, many of the boreal forests have been subject to intensive silviculture for centuries, and this has led to a homogeneous forest structure with even-aged and single-species forests dominating. This structure may be expected to continue and even to become more widely adopted as a consequence of policies aiming to increase harvesting for pulp, timber and bioenergy, but contrasts with the need to manage forests with the aim of increasing their adaptation capacity (Gauthier *et al.*, 2015). Management strategies such as continuous-cover silviculture, integrated with increasing tree species diversity and landscape heterogeneity, offer alternatives that simultaneously contribute to the maintenance of forest cover, the conservation of carbon stocks, and the support of biodiversity and social and cultural values. Additionally, new research calls into question whether the economic viability of boreal forests is dependent on clear-cutting (Tahvonen and Rämö, 2016). Continuous cover forestry – when skilfully combined with existing forest management options – can contribute to stand and landscape heterogeneity and simultaneously provide ecologically and socially beneficial outcomes.

### Box 8 Temperate forest policies (multi-functionality)

On 24 October 2016, organisations connected to forests and wood in **the Netherlands** released a 'National Action Plan Forest and Wood', which was endorsed and signed by the Prime Minister at a National Climate Summit. Organisations representing forest owners, non-governmental organisations and industry proposed measures that will lead to reduced carbon dioxide emissions from the Netherlands, sequester carbon dioxide and provide more renewable woody materials. The plan envisions afforestation of 100,000 hectares, better forest management in 200,000 hectares, establishment of reserves on 20,000 hectares and increased building with wood in the housing sector. The plan will lead to an additional 4 million tonnes of carbon sequestration and an additional supply of 0.8 million m$^3$ of quality wood to the industry. The locations of the various actions are shown in the figure below.



*Envisioned diversity of actions as proposed in the Netherlands Action Plan (Nabuurs et al., 2016.)*

In one example of the continental area of the temperate zones, the **Austrian** Forest Strategy 2020 aims to guarantee the sustainable management and maintenance of Austria's forests, through debate and consensus generation among all stakeholders. The overall objective is to ensure and optimise the ecological, economic and social dimensions of SFM in a well-balanced manner. It aims to increase the value and potential of the Austrian forestry and timber industry and ensure that forests can continue to effectively perform their natural 'functions', such as regulating the microclimate and acting as a carbon sink, for present and future generations.

To this end, policies and targets are being developed in the following seven areas: (1) contributions to climate protection; (2) health and vitality; (3) productivity and economic aspects; (4) biodiversity; (5) protective functions; (6) social and economic aspects; (7) Austria's international responsibility for SFM.

## 5.2 Temperate forests

In the Atlantic area of the temperate region, one example of a national plan involving multi-functional objectives can be seen in the Netherlands (Box 8).

Forests in the continental region of Central Europe (see an example from Austria in Box 8) have suffered frequent wind damage in recent years, and mature trees in an even-aged forest with homogenous structure tend to be more exposed to windthrow than uneven-aged, mixed, heterogeneous forests. Transforming single-species forests into mixed forests and converting them into highly structured uneven-aged forests that are then managed in a continuous-cover (close-to-nature) forestry system, may thus increase the resilience of Central European forests against natural disturbances and climate change impacts (Brang *et al.*, 2014). Silvicultural measures such as reductions in rotation times (traditionally long in parts of Europe) may decrease the vulnerability towards storm and insect damages, as old and large trees are often more vulnerable (Meilby *et al.*, 2001; Schmidt *et al.*, 2010). This is because shorter rotation times would lead to lower tree heights and reduce storm damage risks on exposed sites, while younger trees are less prone to insect attacks and diebacks from climatic extremes. Such

**Box 9 Mediterranean forest policies (multi-functionality)**

Portugal has a high percentage of forested area, having increased from 7% in the 1870s to 35% in 2015. The predominant species are *Pinus pinaster*, *Eucalyptus globulus*, introduced in 1852, and two oak species, *Quercus suber* and *Quercus rotundifolia*, that form the highly productive and biodiversity-rich 'montado' ecosystem. Forest fires have been a recurring problem since the 1970s, accounting for an average annual burnt area of 106,000 hectares from 1980 to 2015. This trend has implied an average annual loss of total forest area of about 10,000 hectares per year in the past 15 years.

Recently, the Portuguese Government released a legislative package for improved forest management and planning, reforestation, afforestation, forest fire prevention and fighting, which is under public discussion. The new legislation addresses the challenges of forest adaptation to climate change and ways to improve the forest contribution to carbon sequestration. The LULUCF sector in Portugal contributed an average annual sequestration of 10.8 million tonnes $CO_2e$ in the period 2011–2015 (UNFCCC, 2016). Recent research has shown that the Mediterranean forest is already being affected by climate change (IPCC, 2014) and that the montado in the southern part of the Iberian Peninsula is particularly vulnerable to high-end climate scenarios that go above the Paris Agreement 2 °C increase in temperature (Guiot and Cramer, 2016).

a policy would, however, have trade-offs with carbon storage and biodiversity (which would be improved by longer rotation periods (Yousefpour and Hanewinkel, 2009)). Some traditional forest management methods such as coppicing and wood meadows or non-intensive forms of tree and group selection forest management, used in Central European countries to different degrees, can also promote high species and structural diversity. Selection cutting maintains continuous cover forestry and an uneven-aged structure (Appleton and Meyer, 2014), and its non-intensive forms can be considered as close-to-nature forestry; it does, however, require a highly skilled work force.

## 5.3 Mediterranean forests

In Mediterranean forests, a change in thinning regimes (density management) to earlier and more intensive thinning to improve water use efficiency of trees has the potential to lessen drought stress, fire risk and vulnerability to insects (Chmura *et al.*, 2011; Giuggiola *et al.*, 2013). Priorities in Mediterranean countries are thus likely to differ from those in other regions (an example from Portugal is shown in Box 9). Fire and pest management with an intensive pest- and disease-monitoring system is an important part of an integrated forest management and adaptation strategy in Central and Southern Europe. In Portugal, France and Spain, fire management using prescribed burning to reduce fuel availability together with other fire-suppression practices are applied under specific legal frameworks (Portugal and France) with specialised teams and a national system for professional accreditation. 'Clean management' and early salvage cuttings after storm damage can also diminish the risk of large-scale bark beetle outbreaks, although such measures run counter to the need to increase deadwood pools in support of biodiversity targets. Bolte *et al.* (2009) have proposed an integrative management approach that would combine species suitability tests and larger-scale modelling, with priority mapping of adaptation strategies at the national, regional and local scales. However, the lack of harmonised data is currently a major obstacle for implementing such an approach.

In summary, although the forests in different parts of Europe are historically very different, analyses lead to a common conclusion that their future resilience would be improved by maintaining and improving forest variability, which includes mixed-species forests and genetic diversity, and using varying silvicultural methods. To meet the objectives of the Paris Agreement, rapid and firm actions to sustain or increase forest carbon stocks are required, and the same applies for biodiversity targets. In Northern European forests, intensive management practices aiming to produce wood may compromise the potential that exists for increasing forest carbon storage and simultaneously their biodiversity. Including the values of carbon flows and pools requires increases in planting density, reducing intermediate thinning and implementing longer rotation periods than in traditional silviculture. Selecting tree species that are adapted to the local conditions, changing thinning regimes or shortening rotation periods may be beneficial for preventing fire and storm damage in parts of Central European and Mediterranean forests, although the last two may have a negative impact on biodiversity.

# 6 Conclusions

This report has been compiled from the perspective that society places many demands on forests, which can rarely all be achieved from the same forests at the same time. Conflicting demands imply the need for choices to be made. These include choices that can be managed through economic supply and demand; for instance, determining the balance of supply between saw logs and feedstock for a biorefinery. However, conflicts and trade-offs between different forest functions are more difficult to manage—especially when traditional markets do not attach a value or provide incentives to manage them. In particular, these shortcomings are relevant to ecosystem services including climate regulation and biodiversity. The aim of this report has been to explore evidence of trade-offs and synergies between the different functions and services offered by forests, and support policy-makers and others in developing policies that are consistent with sustainable and multi-functional use of the EU's forests.

The EU Forest Strategy (2014/2223(INI)) adopts the subsidiarity principle and confirms that '*the competence of the Member States in this area must be respected*'. This strategy reflects the long history of local forest management described in Chapter 1, but the issues focused on in this report extend beyond national borders, straddle the EU, and cannot all be solved through uncoordinated national measures alone. In particular, global issues such as climate change and biodiversity decline demand stronger coherence, joint strategies and management measures, where national policy targets and actions need to be consistent with European and global targets. As is highlighted in Chapter 5, national policies attach different priorities to the various forestry functions, and there are examples where increased use of forestry resource will reduce the carbon stock in the short term, while others are seeking to increase carbon stocks. The pan-European and global nature of some of the EU's commitments require a high degree of coherence between EU and Member State policies.

One notable characteristic of European forests is that they are growing with an annual increment of wood amounting to 720 million $m^3$ (Forest Europe, 2015). However, this growth is interpreted very differently by different stakeholders. On the one hand, some see the increment as a substantial contribution to Europe's efforts to mitigate climate change and the increased carbon stock as not only needing to be protected but enhanced further. Others see it as a resource which should be better used. Resolving such conflicting viewpoints and special interests places a particular challenge on European policy-makers, and EASAC hopes this report may contribute to the associated policy debate.

This is, however, against the background that the effects of climate change on European forests are already being seen, while the EEA (2017) concludes that the relative importance of climate change as a major driver of biodiversity and ecosystem change is likely to increase further in the future. In addition to the direct impacts of changing climate, human efforts to mitigate and adapt to it can both positively and negatively affect biodiversity and other ecosystem services, so that new forest management tools are required to adapt to changing conditions and to maintain the sustainable functioning of forests.

Before considering specific policy options, policy-makers need to recognise that the timescales involved in forest management and its impact on the environment are long—often exceeding 100 years. Today's mature forests were planted decades ago; equally, what we do with forests today will be influencing ecosystems and society for decades into the future. Changes in policies that are expected to have a large-scale impact on European forests should therefore be carefully considered, as it may take a long time before their full impacts become evident. For example, it may be possible to increase timber output quickly through harvesting some of the remaining old-growth forests, but reversing that would take more than a century and, in the case of endangered species, the consequences may be irreversible. For such reasons, it is important to reflect the multi-functionality of forests both in national and in European policies.

The principles of SFM applied in the EU recognise the multi-functionality of forests. SFM aims to maintain the ecological functions of forests and their ecosystem services while fulfilling the economic and social functions that provide many benefits, including a mix of wood-based products and services that provide opportunities for rural job creation, not only in industries making forest products, but also in other forest-related activities and businesses such as tourism. Our analyses do, however, show tensions between some of the six criteria for SFM (see Box 2). One example is between demands for increased extraction of biomass from forests (criterion 3) and the contributions made by the same biomass *in situ* to criteria 2, 4 and 5 (soil fertility, biodiversity and protective functions). Other synergies and trade-offs exist in the way in which forests' interaction with climate change mitigation is managed (criterion 1), and synergies through more diverse ecosystems being more efficient in providing climate change mitigation (criteria 1, 3 and 4). In the latter context, policy options such as logging residue removal, conversion of tree species (native or introduced, exotic) or changed rotation times will often be in conflict with biodiversity goals in traditionally managed production forests (Moen *et al.*, 2014; Felton *et al.*, 2016). Forest managers faced with such decisions should take into account the important role of biodiversity in the resilience, regulation and multi-functionality of forests (Van der Plas *et al.*, 2016a, 2016b).

Critical issues and messages to emerge from the previous chapters are summarised below.

### On forest management

- Adaptive management to strengthen resilience to climate change should prioritise less susceptible species, ensure genetic diversity to increase resilience, and design forest regeneration and harvesting schemes to take into account new risks. Transforming single-species stands to mixed stands will probably provide greater vitality and resistance against abiotic and biotic disturbances (for example diseases, pests, fires and storms).

- Private forest owners increasingly recognise the multiple use of forests: not just as a source for timber or other raw materials, but also as sources for recreation, conservation of biodiversity, landscape elements as well as climate change mitigation. This is generating a need for a new diversified forest management approach that potentially conflicts with policies that intensify the use of forests for the provision of raw materials.

### On forests and biodiversity

- The role of forests is particularly important for biodiversity. The main threat for endangered forest-dwelling species is the limited amount and highly fragmented nature of the remaining natural forests; protection of the current conservation areas should thus be maintained (land sparing) and combined with land sharing in multi-use landscapes to strengthen conservation activities.

- Meeting the targets in the CBD requires coordination between Member States to coordinate national decisions on protected areas. For example, in support of biodiversity objectives, 'corridors' might be established between forest areas in different countries to meet the needs of specific species. Forest management has a crucial influence on species living in forests. Maintaining/improving biodiversity requires both the protection of remaining old-growth and ancient forests, and increases in the amounts of deadwood and other structural elements in managed forests. Negative ecological impacts of management can be avoided by appropriate multi-scale planning and the introduction of new instruments such as payments for ecosystem services. Existing models in some countries should be evaluated for their potential application in a wider European context (Farley *et al.*, 2010).

- Management should recognise that biodiversity underpins the ecosystem services of forests and is linked to their productivity. A decline in biodiversity threatens the ability of both managed and natural ecosystems to adapt to changing conditions and hampers the provisioning of ecosystem services. We can identify several climate change adaptation and mitigation strategies, including continuous cover forestry, conversion to native broadleaf tree species, and increased rotation times, which are largely consistent with biodiversity goals, improving habitat availability in managed forests, and furthermore provide almost equal or sometimes higher revenue for forest owners (Kuuluvainen *et al.*, 2012; Felton *et al.*, 2016; Tahvonen and Rämö, 2016).

### On forests and climate change mitigation

- The climate impact of forests and forestry includes both GHG effects and biophysical effects. Climate effects through albedo or influencing the hydrology cycle (including volatile organic compounds and microbes which trigger clouds) may be as important as the role of forests in carbon management. These should be taken into account in climate change mitigation actions, or there is a risk of mitigation projects that provide little climate benefit or, in the worst case, are counter-productive and costly. Extending management options to mixed evergreen–deciduous stands seems to be a low-risk diversification strategy for incorporating biophysical effects.

- The Paris COP21 targets may not be reachable without sustaining or increasing carbon storage in existing forests. There is a real danger that present policy over-emphasises the use of forests in energy production instead of increasing forest stocks for carbon storage. A more balanced and economically efficient policy is needed. The 'cleaner earns, polluter pays principle', suggesting that carbon storage (i.e. negative emissions) should be subsidised and emissions from forest bioenergy should be accounted for and controlled through appropriate means, could provide cost-effective incentives for forest management and the use of wood.

### Revision of LULUCF reporting

- A critical feature in the emerging EU policy is how the future *forest reference levels* for Member States are specified. These should be set on scientifically objective grounds; otherwise there is a danger that inappropriate specification of forest reference levels will lead to emission transition between different EU categories without any real decrease in adverse climate effects. In the worst case, such perverse transitions could be promoted by public subsidies.

### Objectives of climate and energy policy (forest biomass)

- The initial proposals in the Commission's 2016 energy package (EC, 2016a) already take into account many of the core scientific issues examined in this report (see Box 6)—in particular the critical issue of payback times inherent in the concept of carbon neutrality. The extent to which these are reflected in revisions to the RED and LULUCF rules will be influenced by further debate within the European Parliament and Member States. While such debate needs to take into account a range of factors (supply security and costs among them), EASAC advocates that the most important consideration should be the overall impacts on atmospheric concentrations of GHG, and a requirement to make a positive contribution to climate change mitigation over a climate-relevant period.

### On the timescales to be considered in assessing climate impacts

- The potentially very long payback periods for forest biomass raise important issues given the UNFCCC's aspiration of limiting warming to 1.5 °C above pre-industrial levels to '*significantly reduce the risks and impacts of climate change*'. On current trends, this may be exceeded in around a decade. Relying on forest biomass for the EU's renewable energy, with its associated initial increase in atmospheric carbon dioxide levels, increases the risk of overshooting the 1.5°C target if payback periods are longer than this. The European Commission should consider the extent to which large-scale forest biomass energy use is compatible with UNFCCC targets and whether a maximum allowable payback period should be set in its sustainability criteria.

### Life cycle assessment for forest biomass

- To make an accurate assessment of the climate impacts of bioenergy projects, the life cycle assessment changes emerging under the 2016 revisions to the RED should include changes in the carbon stock of a forest and carbon sequestration that will be foregone as a result of forest biomass use. Expanding life cycle assessment to include carbon stock changes may also need to consider interactions between bioenergy demand and forest management. Here there is some debate on the extent to which forest owners may, with access to bioenergy markets, better protect and manage their forests and invest in forest stocks (Daigneault *et al.*, 2012).
- With substantial imports of forest biomass taking place into some Member States, allowing biomass energy emissions to be counted as 'zero' emission in the consuming country gives a false impression of that country's progress towards reducing climate forcing, since the emissions are merely shifted to another category or country. The climate impact of GHG emissions is not related to location and thus this separation lacks any significance from a climate perspective. EASAC thus welcomes the European Commission's intention that emissions of biomass used in energy will be recorded and counted towards each Member State's 2030 climate commitments, and that more robust accounting rules and governance for forest management will provide a solid basis for Europe's future post-2020 renewables policy.

### Defining sustainability criteria for forest biomass

- Using forest biomass for energy requires science-based standards to avoid deleterious effects on climate, since the wide range of bioenergy scenarios includes those where burning forest biomass releases significantly more carbon dioxide per unit of electricity generated than fossil fuels over extended periods. Regulations and governance should be designed to ensure that forest biomass energy makes an effective contribution to climate change mitigation.

- EASAC supports the adoption of a cascading approach to improve the climate mitigation potential of forests and their sustainable use. Using wood in durable commodities and construction stores carbon over long periods, and substitutes for materials that have a high carbon footprint (steel, concrete, etc.). It may also be further recycled at end of life for further material or biorefinery applications before ultimately being used for energy recovery. Such cascading use offers mitigation potential and promotes greater circularity and the creation of added value (Muys *et al.*, 2014).

- EASAC concludes that scientific knowledge is sufficient to allow the general characteristics of feedstocks to be defined and to avoid the use of biomass with long payback periods. Although, historically, most forest biomass used in Europe for bioenergy has been an integrated part of forest management (scenario 1 in section 4.1) with short payback periods, expanding extraction of biomass or felling primarily for bioenergy (scenarios 2 and 3 in section 4.1) requires criteria to be applied to avoid negative effects on climate persisting for long periods. For instance, the Netherlands introduced legislation to require sustainability criteria for forest biomass pellets[24]. The critical factor is to restrict economic incentives to cases where overall GHG emissions (including biogenic emissions) are fully accounted for and shown to contribute to climate change mitigation in a climate-relevant timescale.

### On the role of biomass in renewable energy policy

- Biomass energy is significantly less effective in reducing atmospheric concentrations of carbon dioxide than other sources of renewable energy. For instance, the carbon payback time for wind and solar lies between a few months to a few years (Marimuthu and Kirubakaran, 2013), instead of the years to decades (even centuries) for forest bioenergy. Policy-makers should re-examine environmental credit rules and associated subsidies to link financial incentives to the real contribution of each technology to climate change mitigation.

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[24] On 18 March 2015, the Dutch energy sector and non-governmental organisations agreed upon the sustainability criteria for biomass. On 30 March, these requirements were laid down in official Dutch legislation. Wood pellets that are used for the subsidized generation of heat or electricity must be produced in compliance with this legislation, which applies limits to the percentage of total woody biomass extracted in any given year and area, disallows conversion of (semi-natural) forests and requires evidence that carbon stocks in forests are being maintained or increased.

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# Annex 1 Expert group membership

## Chairperson

Professor Jaana Bäck, Helsinki University, Council of Finnish Academies

## Members

Dr Réka Aszalós, Institute of Ecology and Botany, Hungarian Academy of Sciences
Professor Reinhart J. M. Ceulemans, University of Antwerp, Royal Academies for Science and the Arts of Belgium
Professor Gerhard Glatzel, Institute of Forest Ecology, Austrian Academy of Sciences
Professor Marc Hanewinkel, University of Freiburg, German National Academy of Sciences Leopoldina
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Professor Otso Ovaskainen, Helsinki University, Council of Finnish Academies
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Dr Marcus Schaub, Swiss Federal Research Institute WSL, Swiss Academies of Arts and Sciences
Professor Olli Tahvonen, Helsinki University, Council of Finnish Academies
Professor Timo Vesala, Helsinki University, Council of Finnish Academies
Dr William Gillett, EASAC Energy Programme Director
Professor Michael Norton, EASAC Environment Programme Director

EASAC also acknowledges the assistance of Dr Nuria Altimir, University of Helsinki

# Annex 2 Glossary

| | |
|---|---|
| CBD | United Nations Convention on Biological Diversity |
| COP | Conference of the Parties |
| EEA | European Environment Agency |
| EFI | European Forestry Institute |
| ESR | Effort Sharing Regulation |
| EUFORGEN | European Forest Genetic Resources Programme |
| FAO | Food and Agriculture Organization of the United Nations |
| FSC | Forest Stewardship Council |
| GHG | Greenhouse gases |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| JRC | Joint Research Centre |
| LULUCF | Land use, land-use change and forestry |
| NET | Negative emission technology |
| PEFC | Programme for the Endorsement of Forest Certification |
| RED | Renewable Energy Directive |
| SRC | Short rotation coppicing |
| SFM | Sustainable forest management |
| TEEB | The Economics of Ecosystems and Biodiversity |
| Tg | Teragram (one trillion ($10^{12}$) grams, equal to one million tonnes) |
| UNFCCC | United Nations Framework Convention on Climate Change |

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For further information:

EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Postfach 110543
06019 Halle (Saale)
Germany

tel +49 (0)345 4723 9833
fax +49 (0)345 4723 9839
secretariat@easac.eu

EASAC Brussels Office
Royal Academies for Science and the
Arts of Belgium (RASAB)
Hertogsstraat 1 Rue Ducale
1000 Brussels
Belgium

tel +32 (2) 550 23 32
fax +32 (2) 550 23 78
brusselsoffice@easac.eu

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