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EUROPE'S WOOD SUPPLY IN DISRUPTIVE TIMES

An evidence-based synthesis report

Editors: Carola Egger, Nelson Grima, Michael Kleine, Maja Radosavljevic

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IUFRO
Interconnecting Forests, Science and People



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Preface

In the face of climate change, geopolitical disruption, and current demographic developments, the future supply of wood from European forests has become a highly relevant topic of interest for many stakeholders. The urgency of this issue has unveiled itself in recent years more than ever before. It is indispensable that effective measures are implemented already now to respond to current and future changes. However, to enable meaningful actions, a solid evidence base is crucial.

Against this background, a group of internationally renowned experts from across a range of scientific backgrounds and disciplines carried out this comprehensive study titled ‘Europe’s wood supply in disruptive times’ in the framework of the science-business platform TEAMING UP 4 FORESTS. When analysing the existing scientific evidence and preparing this study, the authors were guided by the questions identified at Think Tank Meetings and a Stakeholder Dialogue convened by the platform. This study does not only illuminate individual aspects of the availability of wood but also provides an overall picture of multiple factors influencing wood supply and their complex interrelationships. Furthermore, the second part of this publication has a strong implementation-oriented focus which empowers stakeholders to truly put science into practice.

Since 2017, IUFRO has engaged in the crucial dialogue between science, business and other stakeholders in the forest sector and initiated, together with Mondi, an official platform for this specific purpose in 2021 under the name TEAMING UP 4 FORESTS. This platform allows us to convene think tanks and stakeholder dialogues on the most pressing challenges for wood-based industries. Insights from these discussions are included in a separate chapter of this report. In line with the principles of TEAMING UP 4 FORESTS, the highest standards of scientific quality, integrity and independence have been applied when carrying out this study.

My sincere thanks go to the Chair of the study expert group, Metodi Sotirov, the study coordinator and project manager Carola Egger and the content editors Nelson Grima, Michael Kleine and Maja Radosavljevic. I would furthermore like to thank all authors that contributed to this publication for their excellent work and collaborative efforts. Each member of the team contributed with their specific expertise to shed light on a multitude of aspects related to wood supply in Europe. This unique constellation showed how interdisciplinary research collaboration can be key in addressing complex challenges such as the future of Europe’s wood supply. I would like to sincerely thank Mondi for the funding provided for this study.

It is my sincere hope that executives in the wood-based industry, forest owners and managers, policy- and decision-makers and other key stakeholders in the forest and wood-based sector will find the information presented useful.

Alexander Buck
IUFRO Executive Director

Acknowledgements

This publication is the product of the collaborative work of the TEAMING UP 4 FORESTS study expert group. We extend our heartfelt appreciation to all authors and contributors for their valuable work. We sincerely thank the study Chair Metodi Sotirov for guiding the scientific development of this publication with his expertise and leading the study expert group in their work. Furthermore, we would like to thank the following members of the expert group: Ragnar Jonsson, Andreas Nikolaus Kleinschmit von Lengefeld, Andrey Krasovskiy, Florian Kraxner, Manfred J. Lexer, Špela Pezdevšek Malovrh and Anne-Christine Ritschkoff for their contributions. Their dedication, major efforts and great expertise were essential for the preparation of this publication. We also express our appreciation to the institutions associated with the authors, which facilitated their ability to contribute to this product.

We would like to note that the views expressed in this publication do not necessarily reflect the position of the organisations to which the authors are affiliated. We furthermore express our sincere gratitude to Mondi for the financial support provided and the freedom granted to the team of experts conduct the study and produce this publication. As a business partner in the TEAMING UP 4 FORESTS platform, the insights of Mondi provided a valuable indication of the information needs of wood-based industries. At the same time, we would like to note that the views expressed within this publication draw on scientific evidence and expert knowledge, and do not necessarily reflect the position of the forest-based industry in general or the funding company in particular.

Our special thanks go to all participants of the 3 rd TEAMING UP 4 FORESTS Think Tank Meeting – including wood-based businesses, forest owners, public administrations, international organizations, scientists and other stakeholders – that helped us to compile a wide spectrum of different views and stakeholders' perspectives on consequences of potential future developments. In addition, we would like to sincerely thank the IUFRO Secretariat for the administrative support and knowledgeable guidance throughout the development of this report and the work of the expert group.

Carola Egger
Project Manager / Study Coordinator

Nelson Grima
Content Editor

Michael Kleine
Content Editor

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Content Editor

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PRACTICAL IMPLICATIONS AND RESPONSE OPTIONS FOR MULTIPLE ACTORS

List of acronyms, abbreviations, and units

%	percentage
°C	degrees Celsius
AMS	adaptive management scenario
BAU	business-as-usual
BRICS	Brazil, Russia, India, China and South Africa
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CCS	Carbon capture and storage
CEPI	Confederation of European Paper Industries
CEU	Council of the European Union
CHELSA	Climatologies at High Resolution for the Earth's Land Surface Areas
CLT	cross-laminated timber
CO2	carbon dioxide
EC	European Commission
EEA	European Environment Agency
EFTA	European Free Trade Association
EUTR	EU Timber Regulation
EU	European Union
EU28	European Union (28 Member States)
EUDR	European Union Deforestation Regulation
Eurostat	Statistical Office of the European Union
EWPs	engineered wood products
FAO	Food and Agriculture Organization
FAWS	forests available for wood supply
FLEGT	EU Action Plan on Forest Law Enforcement, Governance and Trade
FMPs	forest management plans
FOREST EUROPE	Ministerial Conference on the Protection of Forests in Europe
FRL	forest reference level
FSC	Forest Stewardship Council
FTP	Forest-Based Sector Technology Platform
GDP	gross domestic product
GHG	greenhouse gas
GWMI	Global Wood Market Info
ha	hectares
HWPs	harvested wood products
IAF	International Arrangement on Forests
IIASA	International Institute for Applied Systems Analysis
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ITTA	International Tropical Timber Agreement
ITTO	International Tropical Timber Organization
IUFRO	International Union of Forest Research Organizations
JRC	Joint Research Centre
LULUCF	Land Use, Land Use Change and Forestry
m	metres
m3	cubic metres
MAT	mean annual temperature
mm/year	millimetres per annum
Mm3 SWE	million cubic metres of solid wood equivalent
Mt	megatonnes
NAI	net annual increment
NATURA 2000	European network of protected areas
NGO	non-governmental organisation
ob.	over bark
OECD	Organization for Economic Co-operation and Development
PEFC	Programme for the Endorsement of Forest Certification
PFOs	private forest owners
RCP	Representative Concentration Pathway
RED	Renewable Energy Directive (RED I – Directive 2009/28/EC; RED II - Directive 2018/2001)
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SFM	Sustainable Forest Management
SMEs	small and-medium-sized enterprises
SSP	Shared Socio-economic Pathways
UN	United Nations
UN Comtrade	United Nations Commodity Trade Statistics Database
UNFF	UN Forum on Forests
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change


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Chapter 1

Introduction

Authors: Carola Egger, Maja Radosavljevic, Nelson Grima

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1.1 Background

There is increasing scientific and empirical evidence that *forests*[1], in Europe are strongly affected by climate change, with far-reaching consequences for their health, productivity and ability to provide vital *ecosystem services*, including the supply of wood (FAO, 2022; IPBES, 2018; IPCC, 2023). Tree species of great commercial importance to the *wood-based industry* are being significantly impacted by disturbances such as extreme drought events, bark beetle infestation, and frequent and more intense heatwaves and wildfires (Hanewinkel et al., 2013; Thiele et al., 2017).

In view of these developments, the forest research community has in recent years done a lot of work on projecting how forests in Europe will look by the end of the 21st century. Various comprehensive studies address expected changes in environmental conditions, species composition, susceptibility to disturbances and overall prospects for survival of forests in their present state. Research to date has largely focused on ecological consequences of climate change, and on developing *forest management strategies* that will help build future-resilient forests capable of providing resources to the *wood-based industry*, while still providing other, much-needed *ecosystem services* to society (e.g. Lindner et al., 2014; Rasche et al., 2013; Vauhkonen et al., 2019).

However, climate change is not the only challenge that forests face. It is commonly accepted that many other factors will have a significant impact on the *future of forests* in Europe. For example, the transformation of human infrastructure, alterations in land use, extensive forest harvesting and wildfires in Europe have led to the creation of fragmented forest landscapes (EEA, 2011; Estreguil et al., 2012). Recent research incorporates into future projections such aspects as forest owner behaviour and market trends (Estreguil et al., 2012; Lerink et al., 2023). Although some studies, including the European Forest Sector Outlook Study 2020–2024, provide a wealth of information through the policy lens (UNECE and FAO, 2022), policy-related information on this topic appears to be scattered throughout the existing literature and across various disciplines. Given this background, there is an urgent need for compiling, analysing and summarising existing knowledge – both within and outside academic circles – that deals with the broad spectrum of factors involved in the supply of wood for industrial purposes. A rigorous assessment of this knowledge should be scientifically guided, evidence-based, and implementation-oriented if it is to serve as a tool to inform decision-makers. Moreover, scientific insights need to be combined with specific options for measures in response to the most pressing challenges.

Against this backdrop, in 2021 the *International Union* of Forest Research Organizations (IUFRO), a non-profit and non-governmental international network of forest-related scientists, initiated a partnership with Mondi, a global leader in the packaging and paper industry. One of the fruits of this partnership is the science-business platform TEAMING UP 4 FORESTS, which aims to enhance understanding of climate change impacts on forests and to identify response options in line with the United Nations (UN) Sustainable Development Goals (SDGs). The present study was developed under the framework of this platform.

1.2 Objectives and scope

The main objective of this study is to provide a comprehensive synthesis of existing scientific and technical knowledge on a wide range of factors influencing *wood supply* from European forests, with a special focus on the European wood-based industry. This analysis addresses the severe impacts of climate change on forests and the implications these impacts have for *forest management*, highlighting interconnections with a wide range of policies at various levels, with factors including different conditions under various socioeconomic frameworks, changes in land ownership, and behaviour patterns of forest owners,. Furthermore, this publication explores the current state of innovations and new technologies that further influence the future of wood-based industries. It also identifies potential response options that the wood-based industries, forest owners and forest managers – as well as policymakers, decision-makers and other stakeholders – could apply to ensure the continued supply of wood in Europe and the permanence of the wood-based industry. These potential response options are based on relevant literature, results of empirical research, and discussions with experts and stakeholders from across the forest *value chain*.

Given the complexity of forest ecosystems and their intricate and often unknown interactions with other environmental and socioeconomic systems, the scope of this study was limited to two chief areas: the supply of wood and its deriva-

1 Terms included in the glossary of this report (Appendix I) are written in italics when mentioned for the first time in the text

tives, and aspects related to European forests and European markets. Because of these necessary limitations, a multitude of other essential ecosystem services that forests provide are omitted, such as *non-timber forest products*, carbon sequestration and other regulating services, recreation and other cultural services, and biodiversity conservation and other supportive services. Moreover, the study barely touches on aspects related to wood imports and exports, the dynamics of which are of great relevance to this topic and could therefore be the focus of a new follow-up study, or the main aim of a broader examination of the topic.

1.3 The science-business-stakeholder dialogue approach

As previously stated, the TEAMING UP 4 FORESTS platform aims to bring together the scientific and business communities to share knowledge and find suitable solutions to current and future challenges. An effective way of doing so is to arrange for a continuous dialogue within which all voices can be heard and joint solutions found. Given the magnitude of the challenges at hand in this study, it was deemed necessary to invite to this dialogue not only players from science and industry, but also representatives of other stakeholder groups such as policymakers. The outcomes of this science-business-stakeholder dialogue are synthesised in this publication.

IUFRO – the scientific and impartial half of the partnership that created the platform – was in charge, among other tasks, of designing the study process and preparing this publication to summarise the outcomes of the dialogue in a manner that can be used to inform decision-makers from all stakeholder groups. The team of authors that produced this publication is composed of scientists and other experts from diverse disciplines working on the topics and issues described, with all of them being part of the dialogue in one way or another. The expertise and methods contributed to this publication by the authors was augmented by inputs from an extended group of stakeholders including other scientists, wood-based industry representatives, policymakers and forest owners and manager.

Although this is an evidence-based publication with a strong scientific component, it aims to inform decision-makers that operate mainly outside scientific and academic circles, and to contribute to bridging the gap between science, business and stakeholders in the forest and wood-based sector. Therefore, although parts of some chapters may be more science-heavy – this being necessary to justify inclusion of the issues and explain them – the text is written not for publication by a scientific publisher from the academic community, but to be shared with a wide range of stakeholders and to be understood by the general public. This also shows that the underlying ambition of this Report is to further the interaction between different groups of stakeholders, so it is both a balanced discussion and an ongoing dialogue. This interchange may allow joint identification of solutions to pervasive challenges and simultaneous perception of multiple interests.

Expert group (authors' team) composed for this study
Photo © Špela Pezdevšek Malovrh

1.4 Overview of the study and structure of this publication

Within the TEAMING UP 4 FORESTS platform, the study brought together representatives of the science and business communities and other stakeholder groups to establish a dialogue in which current and future forest- and wood supply-related issues in Europe were identified, and potential solutions or actions to be taken were devised. So far, the study has generated two main 'end products', which comprise this publication (i.e. an extensive description of the evidence-based knowledge and presentation of potential response options), and a separate summary for the industry sector (i.e. extracts from this publication that refer to the most relevant points for the wood-based industry).

This publication presents the synthesis and outcomes of that study. Although the arranged dialogue among stakeholders is an ongoing process, this Report reflects the processes conducted between October 2021 and December 2023 (TEAMING UP 4 FORESTS Think Tank meetings, literature reviews and synthesis, etc.). The publication is divided into two parts. The first part sets out the scientific analysis and synthesis of factors that influence wood supply from European forests, while the second part describes the practical implications of the results of the first part and lists possible response options for different stakeholder groups.

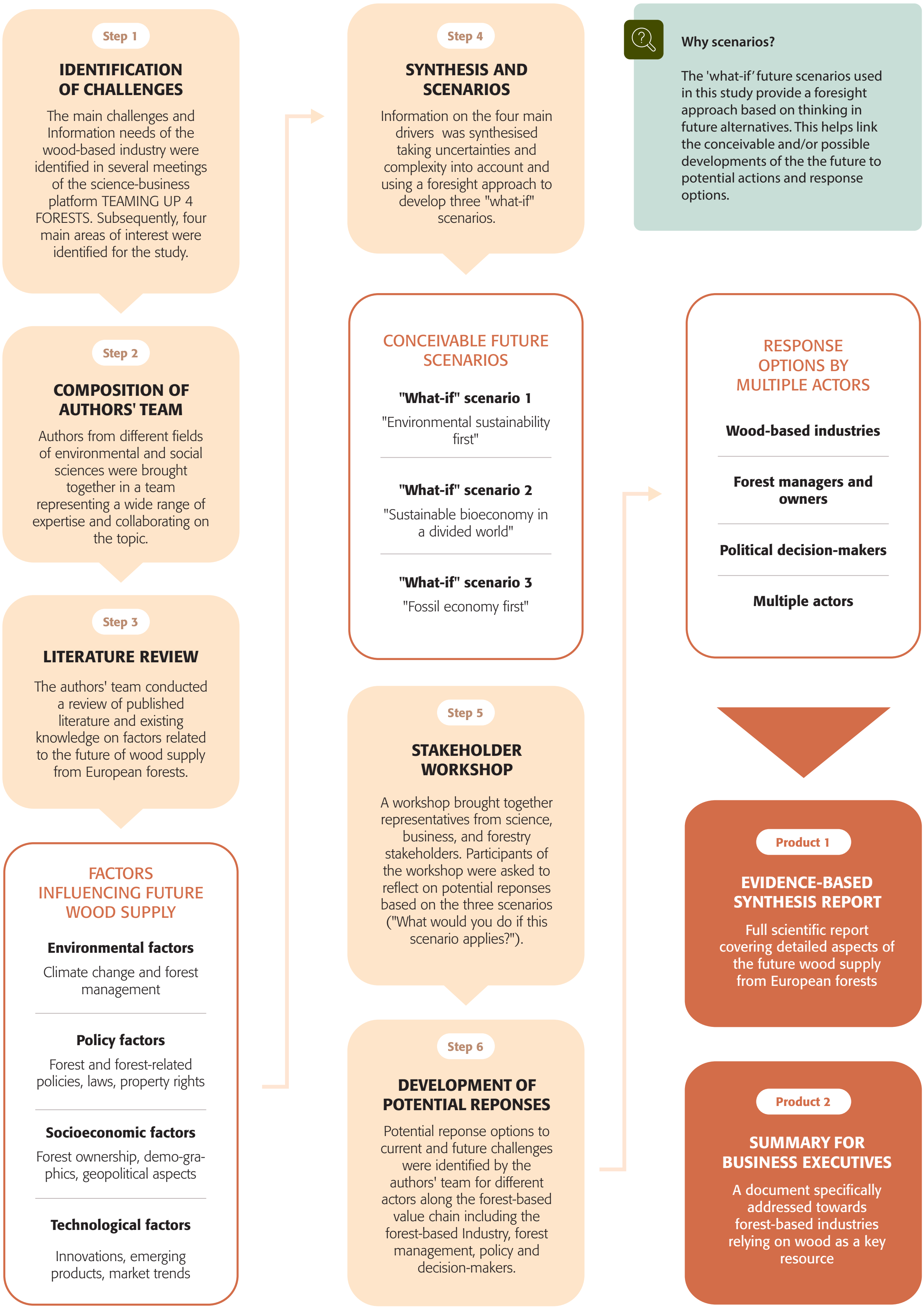
Figure 1 illustrates the process from the initiation of the study until publication of the end products. The study aimed at addressing key information needs and pressing challenges of wood-based industries. These issues were initially identified at several science-business meetings of the TEAMING UP 4 FORESTS platform. Subsequently, a team of scientists and experts was established to author a collaborative analysis of the current knowledge on these issues. The team then conducted a thorough literature review on key factors influencing wood supply in Europe and, based on the knowledge gathered, three future potential *scenarios* were developed to visualise the various factors and their interconnections. Following this work, a stakeholder workshop was held to glean multiple perspectives on potential consequences of these future scenarios. Drawing on the scientific evidence and additional stakeholder insights, the team of authors developed a range of response options for multiple actors by which current and future challenges affecting wood supply in Europe can be addressed, preparing this publication together with an additional summary for wood-based industries.

Figure 2 provides an overview of the structure and main chapters of this publication – an evidence-based synthesis report – which is presented in two main parts. Following a general introduction, the first part of the Report summarises scientific information on key factors influencing wood supply from European forests. This part includes four chapters (Chapters 2–5) that give an overview of those factors. Each chapter tackles one overarching factor and provides a summary of scientific knowledge on the topic addressed.

The second part of the report describes practical implications and response options for multiple actors with regard to the *forest-based value chain* and wood supply. This part begins with Chapter 6, which presents a synthesis of all factors and explores three hypothetical future scenarios building on the evidence described in the first part of the publication. These scenarios are used to show the complexity of future developments, highlight trade-offs, and to help the reader imagine possible future contexts. Subsequently, Chapter 7 provides insight into stakeholders' perspectives on consequences of the future scenarios defined previously. These insights were gleaned at a stakeholder workshop that brought together scientists, business representatives, and other forest-related stakeholders such as policy- and decision-makers, as well as forest owners and managers. To conclude the publication, Chapter 8 presents a compilation of specific response options specifically and separately targeted at wood-based industries, forest owners and managers, political decision-makers and other stakeholders, with Chapter 9 setting out the overall conclusions of the study.

Figure 1

Visual overview of the study



Source: Produced by Egger, 2023

Figure 2

Visual overview of the Evidence-Based Synthesis Report

Evidence-based synthesis report

Europe's wood supply in disruptive times

CHAPTER 1: Introduction – Overview, background, objectives, scope and context of the report

Part 1

SCIENTIFIC SYNTHESIS OF FACTORS INFLUENCING WOOD SUPPLY FROM EUROPEAN FORESTS

The first section of the report provides scientific state-of-the-art knowledge on key factors influencing the future supply of wood and its derivates from European forests. Each chapter focuses on exploring one overarching factor.

CHAPTER 2: Environmental factors – Climate change and forest management

CHAPTER 3: Policy factors – Forest and forest-related policies, laws, property rights

CHAPTER 4: Forest ownership, socioeconomic and geopolitical factors – Changes and developments

CHAPTER 5: Technological and market factors – New developments and emerging wood-based products

Part 2

PRACTICAL IMPLICATIONS AND RESPONSE OPTIONS FOR MULTIPLE ACTORS

The second section of the report provides elaboration on practical implications and reponse options based on the scientific evidence described in Part 1. Part 2 provides guidance to the forest-based sector on addressing key challenges for wood supply from European forests.

CHAPTER 6: Synthesis and future scenarios – Anticipating an uncertain and complex future

CHAPTER 7: Consequences of future scenarios – Statements by stakeholders on potential future actions

CHAPTER 8: Response options – Potential courses of action for multiple stakeholders

CHAPTER 9: Conclusion – Takeaways and reflections on the report

Source: Produced by Egger, 2023

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PART 1

SCIENTIFIC SYNTHESIS OF FACTORS INFLUENCING WOOD SUPPLY FROM EUROPEAN FORESTS

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Chapter 2

Environmental factors

Authors: Andrey Krasovskiy, Florian Kraxner, Manfred J. Lexer

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SUMMARY AND KEY MESSAGES

Forests are highly sensitive to climate change. The natural longevity of trees, and the time needed for forest growth and its associated production cycles in managed forests, do not allow for rapid *adaptation* to environmental changes. This creates a gap between the time needed for adaptation and the current pace of changes in environmental patterns, which may seriously hamper the sustainable supply of wood and its derivatives in the future.

Under predicted scenarios involving current emissions of greenhouse gases (GHGs), temperatures in Europe will increase between 1°C (North Europe) and 3°C (Central/South Europe) within the next few decades; under even more emission-intensive scenarios, temperatures are expected to rise between 2°C (North/West Europe) and 5°C (Central/South/East Europe). Although trends in temperature changes are consistent across various climate scenarios, precipitation is subject to substantial uncertainty. For example, precipitation gains of about 100 mm/year may be expected for North/West Europe, while precipitation losses of up to 400 mm/year are projected for Central/South/East Europe during the second half of this century.

These climatic changes may have substantial impacts on tree growth and productivity, tree regeneration and tree mortality. In mountains and at high latitudes, where temperature is currently a limiting factor, these future climatic changes may be beneficial for forest growth. However, where water is a limiting factor, increases in temperature amplify the negative impacts on tree growth. Extreme weather events will have more drastic effects on forest ecosystems than gradual changes. Moreover, increased occurrence and severity of natural disturbances (e.g. storms, fires, droughts, insects, pathogens) will lead to abrupt tree mortality, which will change forest structures and trigger shifts in forest development processes. This will severely impact the capacity of forests to supply wood and other ecosystem services.

Over recent decades, an increase in both forest area and growing wood volume stock has been registered for many places in Europe, despite increased wood harvesting. The combined effects of carbon dioxide (CO2) concentration, nitrogen deposition, favourable temperature conditions and improved forest management in North Europe and some mountain regions have led to higher growth rates in some areas. However, disturbances such as fires, storms, drought and insect pests increased in both frequency and intensity at the same time. Under a warming climate, forest productivity is expected to increase in Central-West and North Europe, but these productivity gains may be lost due to increasing disturbances. Simultaneously, forest productivity is expected to decrease in Central-East Europe and especially in South Europe, where water limitations, drought and fire are projected to play an even stronger role in shaping future forest development. For example, at European scale the burnt forest area under predicted extreme scenarios is expected to triple and reach 750,000 hectares (ha) per annum by the end of the century.

Depending on different climate change scenarios, the area with conditions suitable for oak species will increase from (at present) 11% to 30–40% of the total forest area in the European Union (EU), while the area suitable for Norway spruce will decrease by about 50%. Human-assisted migration of non-native tree species, or of tree species from more Mediterranean or dry European regions, could have a role in helping to sustain forest productivity. However, some non-native species used in forest plantations such as Douglas fir are known to be extremely sensitive to environmental conditions. Furthermore, a detailed simulation-based study covering 20 million ha of forests indicated that drastic climate change impacts on Central European forests are to be expected in the second half of the century if warming temperatures combine with decreasing water availability. Forests composed of Norway spruce, European beech and Scots pine are considered vulnerable due to their expected increase in tree mortality as a result of intensifying drought conditions. These expected developments require dedicated and rapid forest management-related action concerning the transition of European forests into climate-fit ecosystems. The more extreme the future climate gets, the sooner the implementation of adaptive forest management approaches (instead of current management practices) is needed in order to reduce losses, and to stabilise production and stocks. Non-native but climate-fit tree species could be beneficial vis-à-vis adaptation strategies regarding wood production.

2.1 Our future climate

2.1.1 Introduction and global climate change

Land – encompassing forests, agricultural areas, grasslands and water bodies – is essential for human well-being, offering primary productivity, food, fresh water and various ecosystem services, including carbon sequestration and forest products. According to the *Intergovernmental Panel on Climate Change* (IPCC), human activities, at different levels of intensity, affect about 60–85% of forests and 70–90% of other natural ecosystems (e.g. savannahs, natural grasslands) with a substantial impact on ecosystem service provisioning and biodiversity (Lee et al., 2023).

Furthermore, human-induced climate change has resulted in a warming of the land at a faster rate than the global average, leading to significant effects on land systems. The average temperature over land for the period 2006–2015 was 1.5°C higher than it was between 1850 and 1900, whereas the equivalent global mean temperature change has increased by 0.66°C. These higher temperatures are accompanied by changing precipitation patterns. Temperature and precipitation changes have altered the start and end of growing seasons; they have also contributed to regional crop yield reductions, reduced freshwater availability, subjected biodiversity to stress impacts and increased tree mortality. At the same time, rising levels of atmospheric CO2 have contributed to observed increases in both plant growth and woody plant cover in certain areas such as grasslands and savannahs. While climate change is expected to reduce yields in areas that are already experiencing heat and water stress, higher temperatures can also increase productivity in cooler regions and might open up opportunities for crop area expansion or higher wood yield. However, any overall benefits might be counterbalanced by reduced suitability in warmer regions (Lee et al., 2023; Pugh et al., 2016).

To better understand the impacts of climate change, different trajectories called '*Representative Concentration Pathways*' (RCPs) have been developed by the IPCC. These climate pathways represent a range of possible future scenarios under different degrees of global warming (Lee et al., 2023; Box 1). The climate change scenarios are calculated from assumptions regarding *shared socioeconomic pathways* (SSPs). The latter describe different future developments involving demographic, economic, technological and policy drivers of climate change (Riahi et al., 2017).

Unlike temperature changes, alterations in precipitation are more markedly scattered over the earth's surface when comparing different climate pathways. It is likely that both precipitation gains and losses will occur. For instance, the northern hemisphere might experience precipitation gains in vast areas even under the most moderate climate pathway. In particular, both polar regions and some regions around the equator are projected to face precipitation gains of up to 50 mm/year and more (as an annual average). By contrast, Central America, South Europe and Southern Africa might experience average precipitation losses of up to 30 mm/year (Lee et al., 2023).

Box 1

Brief description of global climate scenarios used in this report

Four main climate change scenarios (RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5), described as Representative Concentration Pathways (RCPs), were developed for the Fifth Assessment Report of the IPCC in 2013 (IPCC, 2014). In this IPCC report, greenhouse gas concentration and radiative forcing form the starting point for climate change projections. RCPs are labelled after a possible range of radiative-forcing values in the year 2100: 2.6, 4.5, 6, and 8.5 W/m2, respectively (Kriegler and Petersen, 2013).

The global 'shared socioeconomic pathways' (SSPs) are, along with radiative forcing, used as a starting point for the simulations. The RCPs consider changes in population, gross domestic product (GDP), energy consumption, policy changes and other factors described in the SSPs. For example, an increase in world population to 12 billion people by 2100 is likely to lead to scenario RCP 8.5 and a tripling of primary-energy consumption. A population of nine billion people by the end of the century would potentially result in the RCP 2.6 scenario. There are also differences in the energy mix with, for example, a very low oil share in RCP 2.6 and a very high share of almost 50% coal in RCP 8.5.

Carbon dioxide emissions will increase from almost 10 GtC/year in the present to almost 30 GtC/year by the end of the century under RCP 8.5, while falling to zero around 2080 under RCP2.6 (van Vuuren et al., 2011).

Modelled temperature projections (Hamburg Earth System Model MPI-ESM; DKRZ, 2013) over the period 2001–2100 for the three RCP scenarios 2.6, 4.5 and 8.5 show that, in scenario RCP 8.5, the increase in global mean temperature by the year 2100 is about 4–8°C compared to pre-industrial times and 4°C compared to 1986–2005. Under the RCP4.5 middle scenario, warming reaches 2.6°C above pre-industrial levels. In the RCP2.6 scenario, on the other hand, the mean global temperature increase remains below the 2°C target under the Paris Agreement that seeks to implement the UN Framework Convention on Climate Change (UNFCCC) (DKRZ, 2013; Müller et al., 2018).

However, global mean values say relatively little about the geographical distribution of the temperature increase. Under the RCP 2.6 scenario the continents do not, across large expanses, show any greater warming. Nevertheless, temperatures would rise more sharply in the interior of the continents and the high northern latitudes, particularly in northern Siberia and northern Canada. Additionally, there are larger differences under RCP 8.5. Levels above the oceans show projected warming up to 4°C compared to the period 1986–2005. However, the Arctic Ocean differs substantially from this, showing expected temperature increases of up to 11°C. Except for narrow coastal strips, temperatures on the continents are likely to be consistently warmer than around 4°C and, in the continental interiors, by as much as 6°C or more.

Precipitation is likely to shift towards an extreme pattern in which dry areas become drier and wet areas become wetter. The RCP 2.6 scenario exhibits the same pattern, though to a lesser extent. Precipitation decreases of up to 25%, and in some cases even more, are projected for the subtropics. At higher latitudes, precipitation is projected to rise by a maximum of 25% and, in the tropics, by more than 100%. Under the RCP 4.5 trajectory, this tendency would increase, so that Southern Europe would be affected by a large decrease in precipitation in summer. And, in the RCP 8.5 scenario, these summertime decreases from Southwestern Europe via the Balkans to Central Asia are as much as 50 to 75% (IPCC, 2014).

Please note that the uncertainties for projections on temperature and precipitation increase with the timeframe of these projections.

Source: 5th IPCC Assessment Report

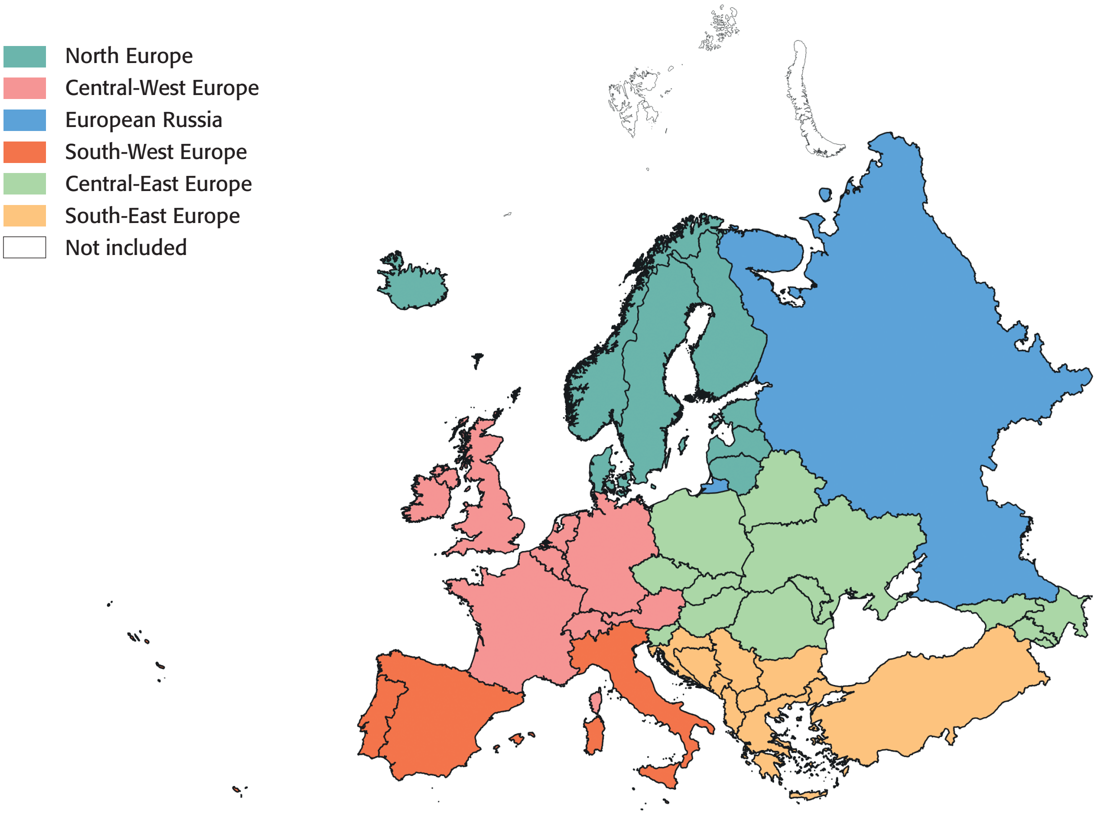
In addition to changes in temperature and precipitation, the number of extreme weather events linked to climate change is expected to rise significantly, resulting in major forest losses with heatwaves and droughts causing more devastating wildfires (Seidl et al., 2017). Historical episodes of observed increases in tree mortality across many world regions have already been attributed to heat and drought stress (Allen et al., 2010; Anderegg et al., 2013). Data records show a net loss of forest and tree cover in the tropics and a net gain of mainly secondary, seminatural and planted forests in the temperate and boreal regions. In addition, changes in land use resulting from climate impacts are expected to rapidly accelerate losses of species diversity (Pandit et al., 2018; Settele et al., 2014; Urban et al., 2016).

2.1.2 Major climate change effects in Europe

To ensure consistency and facilitate comparison throughout this study, European countries have been grouped into six biogeographical regions (Table 1). This classification is based on a map originally developed for the United Nations Economic Commission for Europe (UNECE); see Figure 3. To ensure unbiased mean values of climatic variables, this classification excluded the northern islands.

Figure 3

Six European biogeographical regions used for this study



Source: International Institute for Applied Systems Analysis (IIASA), Krasovskiy and Kraxner, 2023

Table 1

Country allocations to six European biogeographical regions

NORTH EUROPE	CENTRAL-WEST EUROPE	CENTRAL-EAST EUROPE	SOUTH-WEST EUROPE	SOUTH-EAST EUROPE	NOT INCLUDED
▪ Denmark	▪ Austria	▪ Armenia	▪ Andorra	▪ Albania	▪ Franz Josef Land (Russia)
▪ Estonia	▪ Belgium	▪ Azerbaijan	▪ Gibraltar (UK)	▪ Bosnia	▪ Jan Mayen (Norway)
▪ Finland	▪ France	▪ Belarus	▪ Italy	▪ Bulgaria	▪ New Land (Russia)
▪ Latvia	▪ Germany	▪ Czech Republic	▪ Malta	▪ Croatia	▪ Svalbard (Norway)
▪ Lithunia	▪ Gibraltar (UK)	▪ Georgia	▪ Portugal	▪ Greece	
▪ Norway	▪ Guernsey (UK)	▪ Hungary	▪ Spain	▪ Herzegovina	
▪ Sweden	▪ Ireland	▪ Moldova		▪ Macedonia	
▪ Faeroe Islands (Denmark)	▪ Isle of Man (UK)	▪ Poland		▪ Montenegro	
	▪ Jersey (UK)	▪ Romania		▪ Serbia	
	▪ Liechtenstein	▪ Slovakia		▪ Slovenia	
	▪ Luxemburg	▪ Slovenia		▪ Turkey	
	▪ Monaco	▪ Ukraine			
	▪ Netherlands				
	▪ Switzerland				
	▪ United Kingdom				

Source: IIASA, Krasovskiy and Kraxner, 2023

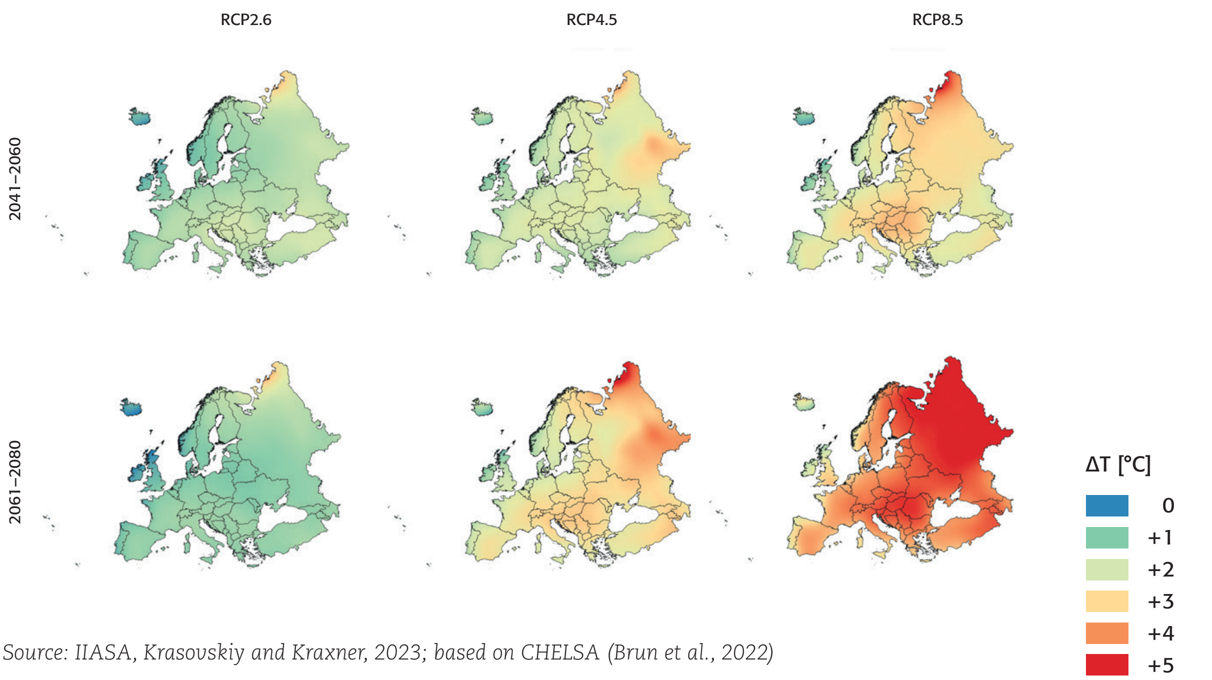
To analyse projections of future temperature and precipitation, the Climatologies at High Resolution for the Earth's Land Surface Areas (CHELSA) dataset has been used by way of representing the earth's land surface areas. For improved visualisation, three time periods have been selected: 1970–2013 as a historical reference period, and 2041–2060 and 2061–2080 as future projection periods. Different bioclimatic variables have been assessed under three different climate pathways (RCP 2.6, RCP 4.5 and RCP 8.5). Temperature and precipitation, with their roles as highly important bioclimatic variables, are further elaborated on below.

Temperature

The results presented in Figure 4 indicate a projected moderate temperature increase of 1–2°C in both time periods under RCP 2.6. Nevertheless, some areas are showing slightly greater warming with increases of 3°C, for example in Northern European Russia and Central Europe / the Alps, particularly during the earlier period. Under RCP 4.5, some temperature hotspot areas (+ 3–4°C) can be found in the earlier period in Northern and Central European Russia. These hotspot areas show further increases in temperature and extend to take in the whole of Europe except the UK and Norway. Under RCP 8.5, however, warming will reach 5°C and above in vast areas of Europe towards the end of the century. Table 2 indicates mean annual temperatures (MATs) averaged for each geographical European region for the two future time periods and the three climate change pathways, as well as their changes relative to the historical period.

Figure 4

Changes (ΔT) in annual mean temperature for future climate scenarios RCP 2.6 (left), RCP 4.5 (centre), and RCP 8.5 (right) and two time periods, relative to the historical period



Source: IIASA, Krasovskiy and Kraxner, 2023; based on CHELSA (Brun et al., 2022)

Table 2

Changes (ΔT) in annual mean temperature for future scenarios relative to the historical period: mean values for regions

TIME PERIODS	1979–2013	2041–2060			2061–2080		
Scenarios	Historical	ΔRCP2.6	ΔRCP4.5	ΔRCP8.5	ΔRCP2.6	ΔRCP4.5	ΔRCP8.5
North Europe	2.86	1.20	1.96	2.44	1.19	2.31	3.88
Central-West Europe	9.64	1.41	1.87	2.36	1.06	2.33	3.52
Central-East Europe	8.62	1.72	2.23	2.92	1.13	2.92	4.50
South-West Europe	13.40	1.53	1.84	2.38	1.21	2.54	3.49
South-East Europe	11.35	1.89	1.97	2.65	1.31	2.83	4.10
European Russia	3.09	1.80	2.52	3.08	1.56	3.33	5.20

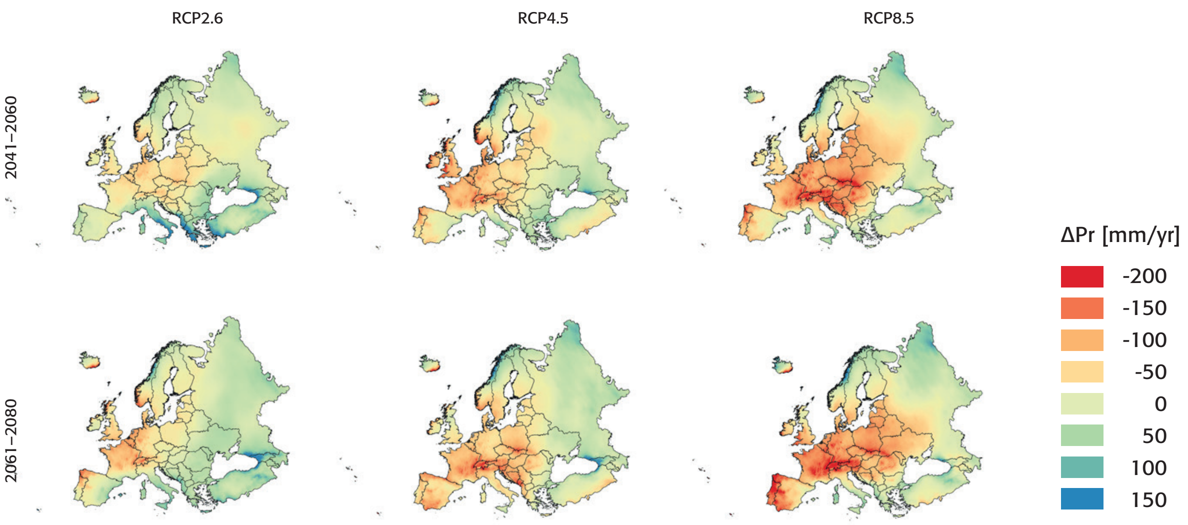
Source: IIASA, Krasovskiy and Kraxner, 2023; after CHELSA (Brun et al., 2022)

Precipitation

Changes in precipitation – another highly important bioclimatic variable – between the time steps and increasing climate change pathways, especially at RCP 8.5 (Figure 5, Table 3), indicate a rather dramatic shift in this aspect of climate. While most areas of Central Europe will lose precipitation on a scale of up to 500 mm, parts of Northern European Russia and the Nordic countries will gain precipitation of around 100 mm annually under the climate change scenarios envisaged. These might – depending on local soil properties, other weather parameters and vegetation – become areas with increasing growth of forest and other biomass. And it is not only changes in amounts of precipitation that should be expected: additionally, changes in precipitation patterns between the annual seasons (e.g. summer vs. winter), and precipitation type (e.g. snow vs. rain) are projected to occur while extreme precipitation (and temperature) events will increase.

Figure 5

Changes (ΔPr) in annual mean precipitation for scenarios RCP2.6 (left), RCP4.5 (centre), and RCP8.5 (right) and two time steps, relative to the historical period



Source: IIASA, Krasovskiy and Kraxner, 2023; based on CHELSA (Brun et al., 2022)

Table 3

Future scenarios – changes (ΔPr) in annual mean precipitation relative to the historical period: regional mean values

TIME PERIODS	1979–2013	2041–2060			2061–2080		
Scenarios	**Historical**	**ΔRCP2.6**	**ΔRCP4.5**	**ΔRCP8.5**	**ΔRCP2.6**	**ΔRCP4.5**	**ΔRCP8.5**
North Europe	732	-5	-14	-21	-18	-10	-11
Central-West Europe	913	-43	-90	-97	-66	-77	-117
Central-East Europe	628	-16	-19	-89	12	-35	-87
South-West Europe	748	23	-31	-51	-8	-71	-84
South-East Europe	697	45	-1	-25	39	-27	-9
European Russia	554	2	8	-11	19	20	8

Source: IIASA; based on CHELSA (Brun et al., 2022)

2.2 The current state of European forests

Total forest area, *forests available for wood supply* (FAWS), and growing stock have all been increasing in the decade 2010–2020 across all regions in Europe. One exception is a small decrease in FAWS in North Europe (-0.01%). FAWS account for below 50% in South Europe, yet in all other European regions the proportion exceeds 70%. This indicates regional differences in productivity as well as other relevant functions. Productivity differences are well reflected in growing stock, in totals and per hectare (Table 4). About 84% of growing stock is located in forests available for wood supply. Variation between countries is high: Liechtenstein (at 409.0 m3/ha), Switzerland (at 353.9 m3/ha), Romania (at 339.8 m3/ha) and Germany (at 320.8 m3/ha) report the highest growing-stock densities, whereas Iceland (at 16.0 m3/ha), Spain (at 59.7 m3/ha) and Turkey (at 74.0 m3/ha) report the lowest. The growing-stock density on *other wooded land* in Europe is 16.2 m3/ha. Different levels of growing-stock density can primarily be attributed to ecological factors that define tree growth (such as site quality and climatic conditions), forest protection measures, forest management practices and, in some cases, local terrain conditions that may restrict harvesting operations (FOREST EUROPE, 2020).

Table 4

Area and growing stock in Europe by region

REGION (EUROPE)	FOREST AREA		GROWING STOCK			
Scenarios	**Total area [1,000 ha]**	**FAWS [1,000 ha]**	**Total area [mill. m3]**	**Total area [m3/ha]**	**FAWS [mill. m3]**	**FAWS [m3/ha]**
North	71,299	55,424	9,195	129.0	7,659	138.2
Central-West	38,966	35,121	9,433	242.1	9,014	256.6
Central-East	44,735	32,382	11,391	254.6	8,841	273.0
South-West	31,466	10,654	1,109	59.7	979	91.9
South-East	40,887	19,124	3,855	115.7	2,195	114.8

EU28*	162,422	120,113	26,470	182.0	22,682	188.8
Europe	227,553	152,703	34,983	169.1	28,688	187.8

*EU28: European Union (28 Member States)

Source: IIASA; based on CHELSA (Brun et al., 2022)

Coniferous tree species account for 58.6% of the growing stock in European forests. The *stem volume* in European forests is evenly distributed between broadleaved and coniferous tree species in almost all regions except North Europe, where 74.4% of growing stock is dominated by conifers. Six genera of tree species represent 83.8% of growing stock: pine, spruce, fir, beech, oak, and birch. These six genera collectively represent 83.8% of the growing stock: pine (29.6%), spruce (23%), beech (11.9%), oak (10%), birch (6.6%) and fir (3.2%) (FOREST EUROPE, 2020).

Table 5

Net annual increment (NAI; gross increment minus natural tree mortality) and felling in forests available for wood supply) in 2015

Region (Europe)	NAI [mill. m3]	Fellings [mill. m3]	Utilisation rate
North	249.1	205.8	0.82
Central-West	259.1	184.7	0.71
Central-East	86.6	53.6	0.61
South-West	–	–	–
South-East	57.5	33.3	0.57
EU28*	576.4	432.2	0.74
Europe	652.3	477.5	0.73

*EU28: European Union (28 Member States)

Volumes are in cubic metres (m^3) over bark (ob.) and represent 67% of forests available for wood supply in the European Union 28 Member States

Source: FOREST EUROPE, 2020

In 2015, wood production in Europe reached a maximum of 477.5 million m3 (Table 5). North and Central Europe's forests remain the leading producers of wood. In particular, Sweden, Finland, Germany, France, and Poland account for above 51% of all wood removals in Europe.

The increased accumulation of growing stock in European forests over the last 30 years is the result of the difference between the total stem volume increment and the total stem volume that was removed from forests during this period. Wood removal occurs either through harvesting of wood or through losses of living stems due to natural mortality including disturbances (e.g. insect infestation, fire, windthrows). Since 1990, the amount of wood felling has markedly increased in all European regions except in South-West Europe. However, because the increase of volume increment has been higher than for felling, the growing stock has increased as well. Utilisation rates of < 1.0 can be explained by the age structure of forests, different market developments, reduced dependence, forest owners' interest in generating an income from wood sales, constant reduction of the share of forestry in the national economies, nature conservation regulations, and increased societal awareness of the multifunctional role of forests (see Chapters 3 and 4). The combined effects of CO2 concentration and nitrogen (N) deposition with favourable temperature conditions in North Europe may lead to increased growth rates, at least within certain regions, in the future (FOREST EUROPE, 2020).

2.3 Climate change impacts on forests

Changes and variations in climate and weather variables will impact forest ecosystem processes and features by means of various causal chains (Box 2). The composition and structure of forests largely determine wood supply. Forests are particularly sensitive to changing climate because of the long lifespan of trees.

Box 2

Key ecological and forest ecosystem variables

KEY CLIMATE AND WEATHER VARIABLES

- Changes in summer and winter precipitation
- Heavy rainfall days
- Annual mean temperature
- Length of growing season
- Heat days, frost days, snow cover days
- Increasing levels of CO2 in the atmosphere
- Annual mean evaporation

FOREST ECOSYSTEM PROCESSES

- Productivity
- Standing stocks
- Tree mortality
- Species composition
- Forest structure

While rising levels of CO2 induce increased photosynthesis rates, this may not necessarily translate directly into increased rates of growth because of other limiting factors such as nutrient availability. The effect of rising temperatures varies between bioclimatic regions. Where temperature is currently a limiting factor such as in mountains and at high latitudes, climate change may be beneficial for forest growth in the future. If water is a limiting factor, increases in temperature would amplify the negative impacts on forest growth. Water availability varies at even smaller scales than temperature, due to differences in the water storage capacity of soils and to varying precipitation levels and patterns (Granier et al., 1996). Nevertheless, extreme weather events have more drastic effects on forest ecosystem processes and features than gradual changes in environmental conditions. Disturbances lead to abrupt changes in forest structure and processes, thus substantially impacting the continuous provision of forest ecosystem services including wood supply. A literature review study found that five out of the six disturbance agents (wind, fire, drought, insects, pathogens) are expected to increase in a warming and drier climate in the future (Seidl et al., 2017).

Increasing disturbances such as forest fires have drastic impacts on forests
Photo © Gilitukha from iStock

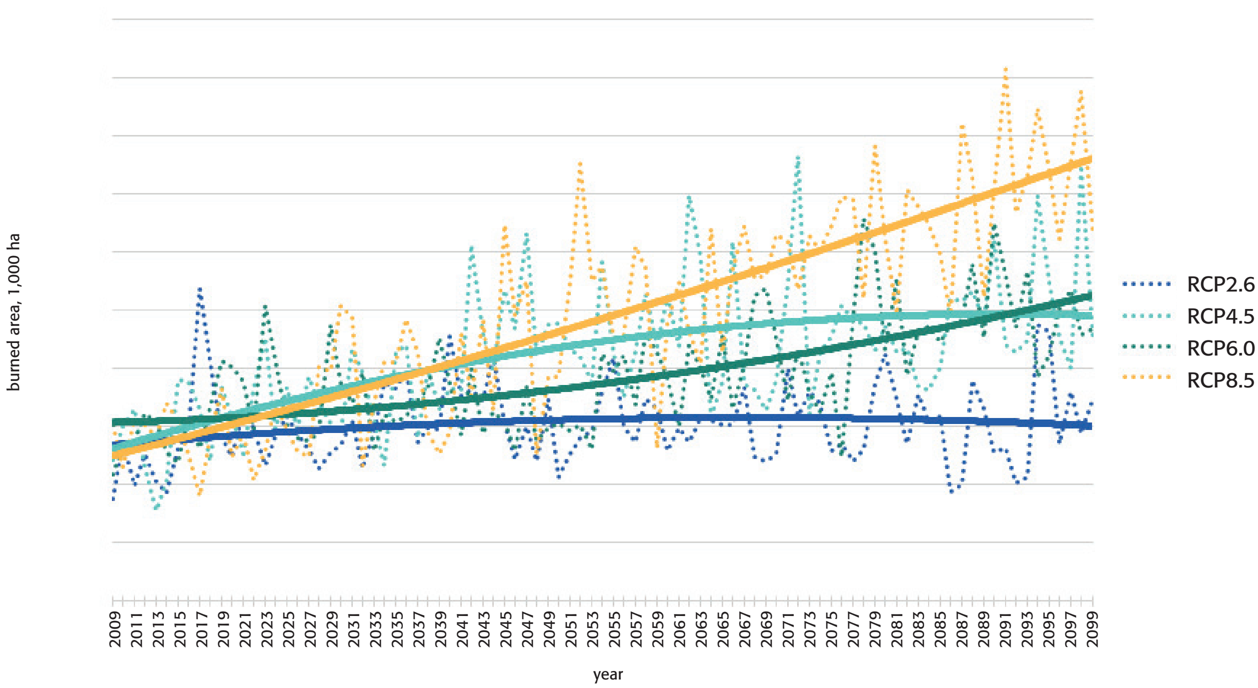
Patacca et al. (2023) found a significant increase in forest disturbance in 34 European countries with a minimum average volume of disturbed and salvaged wood amounting to about 44 million m3 of wood per annum over the period 1950–2019. Wind was the most important disturbance agent, accounting for 46% of total damage, followed by fire (24%) and bark beetle (17%). Bark beetle damage showed a particularly dramatic increase over the last two decades. Large areas of conifers, particularly Norway spruce at low elevations far outside the historical natural range of that species, suffered from heatwaves and drought periods. These trees offered excellent habitats for bark beetle infestation, which themselves were favoured by warmer thermal conditions (Hlásny et al., 2019). With regard to spruce bark beetle, a further increase in damaged wood is anticipated due to the availability of suitable habitats for insects in mountain forests and at higher latitudes within the boreal forests of Sweden, Norway and Finland. While disturbance data shows strong variations in magnitude over time, with large peaks caused by extreme events, the long-term average increase of damaged wood volume was 845,000 m3 per annum between 1950–2019 (Patacca et al., 2023).

Lindner et al. (2010) anticipated that forest productivity would increase in a warmer climate in Central- West and North Europe while decreasing in the Central-East and, especially, in the Southwestern Mediterranean region of Europe due to water scarcity. Productivity gains in Central and Northern regions in Europe would, however, be lost due to increasing disturbance intensity. In the South, drought and fire were expected to play an even greater role in shaping future forest development.

Figure 6 shows the forest area projected to be burnt by wildfire under different RCPs in Europe. The projections indicate an increasing area burned by fire under RCP 4.5, 6.0 and 8.5. Under the most severe scenario, the burned area can be expected to have more than doubled by the end of the century compared to the least severe scenario.

Figure 6

Projected changes in burned areas in Europe under four different scenarios over time (2009–2099)



Source: IIASA, FLAM Model, Krasovskii et al., 2019

Generally, expectations regarding forest disturbance reported in Lindner et al. (2010) have been confirmed so far by empirical evidence. In boreal North Europe, however, the impacts of increasing disturbances caused by insects and drought are found to be greater than initially estimated.

2.4 Effects of climate change and management on European forests in the 21st century

In this section we present a summary of a few existing recent studies, as well as our own contributions, regarding the development of forest productivity, stocks and harvests under different climate change conditions and forest management regimes.

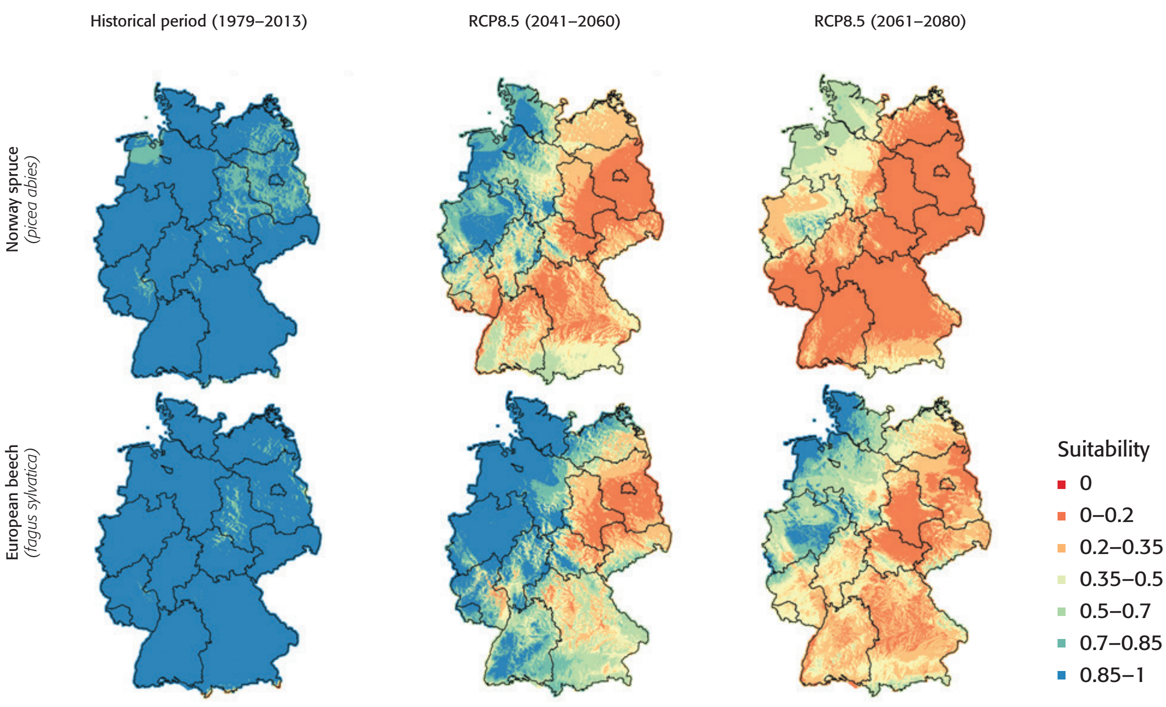
2.4.1 Suitable habitats for tree species

Static species distribution models have been used in several climate change impact studies in Europe. Despite the limitations of this approach (see Chapter 2.5), interpreting the potential implications of the findings is a worthwhile exercise. By estimating the potential range shifts of economically important tree species in European forests, Hanewinkel et al. (2013) found drastic changes in suitable species habitats. Oak species habitat will increase from currently 11% to 30–40% of forest area, depending on climate change scenario, while Norway spruce will have its suitable habitat decreased by about 50%.

To illustrate these findings with examples, Figure 7 shows the changing climate risk in terms of habitat suitability for tree species in Germany under the RCP 8.5 climate change scenario. The *modelling* projections reveal that both coniferous (e.g. Norway spruce) and deciduous (e.g. European beech) tree species will encounter severe limitations in habitat suitability under this severe climate change scenario by the end of the 21st century.

Figure 7

Tree species suitability for Norway spruce and beech historically and at the end of the century under RCP 8.5 in Germany



Source: BioKraft, 2022

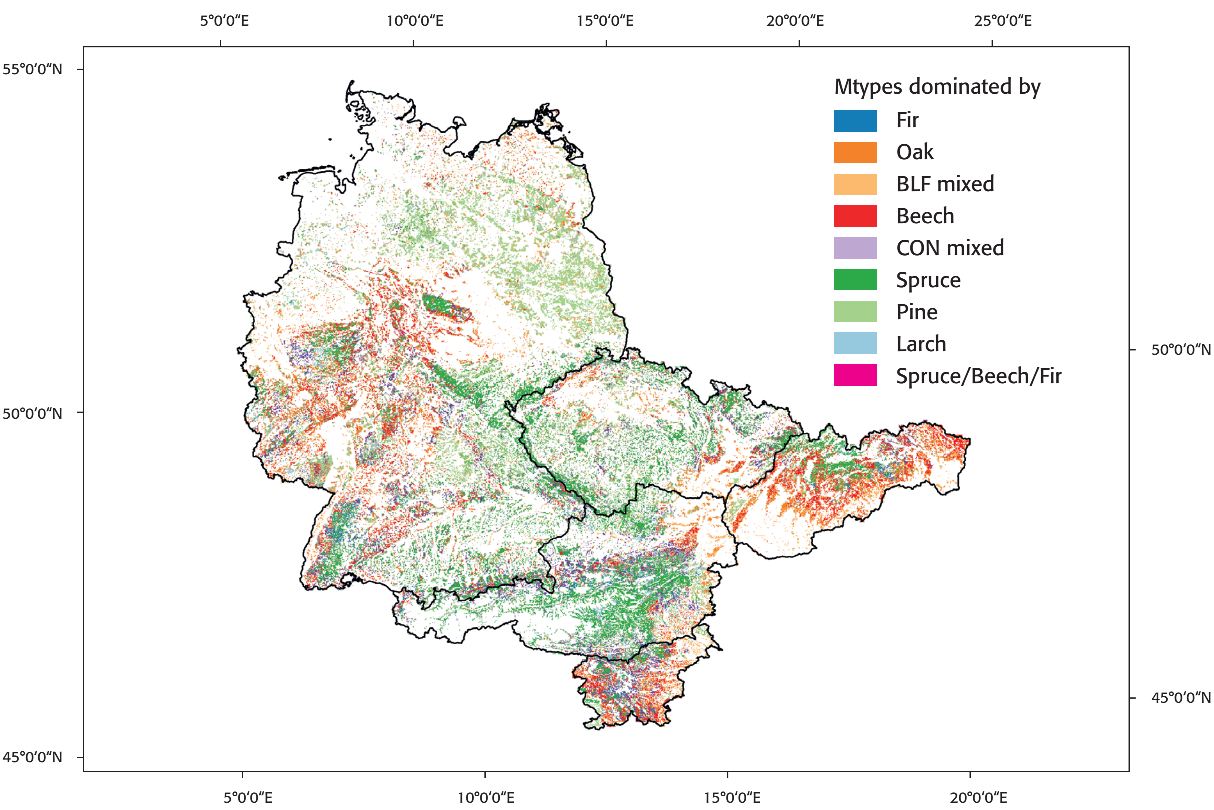
2.4.2 Impacts on wood production

To estimate the impacts of climate change and forest management on wood production, forest development in Central Europe (Austria, Czech Republic, Germany, Slovakia, Slovenia) was simulated with a dynamic forest ecosystem model (Irauschek et al., 2017; Lexer and Hönninger, 2001; Seidl et al., 2005) for the period 2000–2100. Spruce bark beetle and storm disturbances were specifically factored into the simulations. The simulations were run in a full factorial design involving four climate scenarios (historic climate, three climate change scenarios), the current management practices and six adaptive management scenarios (AMSs) (Lexer et al., 2022).

Initial forest state
The initial forest state in the year 2000 for an overall forest area of 19.4 million ha was described based on national forest inventory data at a pixel size of 1x1 km (Figure 8).

Figure 8

Initial forest state in five Central European countries in 2000 based on national forest inventory data



Source: Lexer et al., 2022

Climate change scenarios
The climate change scenarios (further explained in Box 1) represent a range of medium to severe climate change implications for Central Europe. RCP 4.5 would lead to a 1.5°C higher MAT and no significant changes in precipitation totals at the end of the 21st century. RCP 8.5 would result in a MAT increase of 3.4°C and small changes in overall precipitation. In RCP 8.5e, the most extreme scenario, MAT is projected to rise by 4.1°C, accompanied by reduced total precipitation with a decrease of 11% in annual precipitation and a sharp reduction by 50% during the summer season.

Forest management scenarios
Currently applied forest management regimes were operationally defined for the major types of forest mixture based on reports and interviews with experts from the five countries. These management regimes also included non-actively managed forests (albeit only a small proportion).

Five possible forest management response options from the forest owners' and forest managers' perspective (see also Chapter 4) were identified. These included (i.) no management (setting aside forests); (ii.) continuing with current management practices (*business-as-usual* management – BAU); (iii.) replacing Norway spruce stands with mixed broadleaved stands at low elevations and reducing the share of Norway spruce at higher elevations in favour of broadleaves or other domestic conifers (silver fir, larch, pine); (iv.) replacing Norway spruce with Douglas fir and shares of admixed broadleaved species up to elevations of 800 m above sea level; and (v.) shifting to a short-rotation approach in Norway spruce stands at low elevations with planned rotation periods of 60–70 years.

These response options were then combined in six AMSs for the entire forest area in Central Europe: AMS1 combined the mixed-broadleaved approach at low to mid-altitude sites, with both 'no management' and 'BAU management' accounting for a proportion at higher altitudes. AMS2 employed the Douglas fir option at lower elevations, with no management and BAU in another forest area. AMS3-5 used a mix of mixed broadleaved stands, Douglas fir, no management and BAU in varying proportions. Finally, AMS6 continued with Norway spruce forestry in shorter rotations at low elevations and BAU at higher altitudes, including a share of no longer actively managed forests.

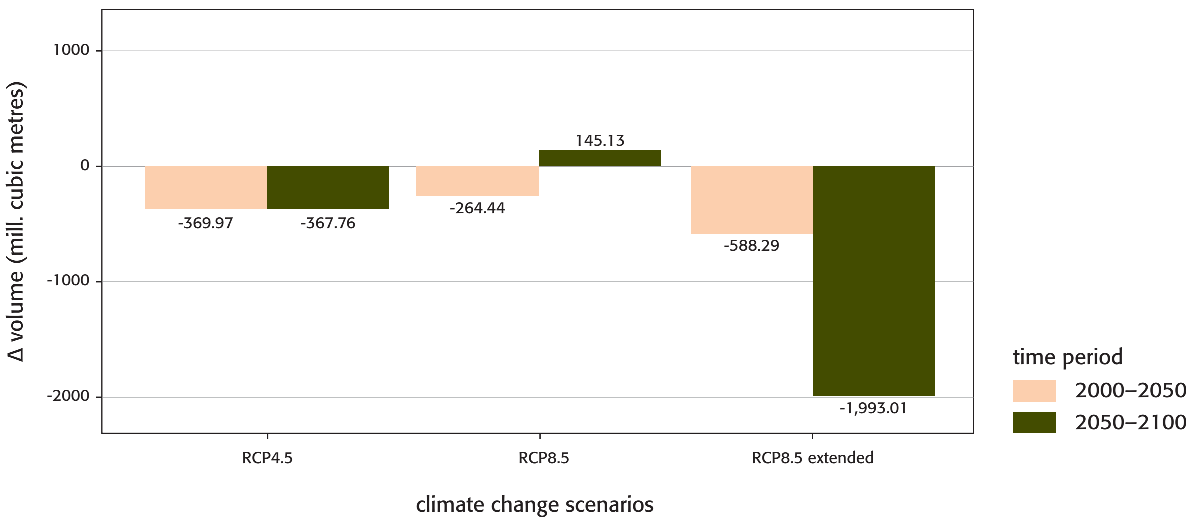
Forest simulation results

To analyse and present the results, the forest area was structured into three elevational zones (> 1,400 m, 800–1,400 m, < 800 m). It is important to note that, in the Central European region, only 18% of the forest area is located at altitudes above 800 m. Assuming no climate change and continued forest management regimes, annual harvests of approximately 150 million m3 are expected, with Norway spruce accounting for 70–80 million m3 of this.

Under the scenario of a moderate temperature increase (up to 3°C by the end of the 21st century) and no changes in precipitation, the projections show a decrease in growth below 800 m altitude and an increase in salvage harvests of damaged wood mainly due to spruce bark beetle. Under climate change scenarios RCP 4.5 and RCP 8.5, standing-volume stocks can be retained. However, if precipitation decreases similarly, this would result in a drastic reduction of forest growth at lower elevations in parallel with a sharp increase in bark beetle disturbances up to 1400 m altitude. Overall, unplanned wood harvests ('salvage logging') over the simulation period would increase by 8.7 million m3 per annum. Stocks would decrease due to reduced increment and high levels of salvage logging (Figure 9).

Figure 9

Mean changes in standing stock (mill. m3 ob.) under three climate change scenarios (RCP 4.5, RCP 8.5, RCP 8.5 extended) and current management compared to historical climate, over two time periods in Central Europe



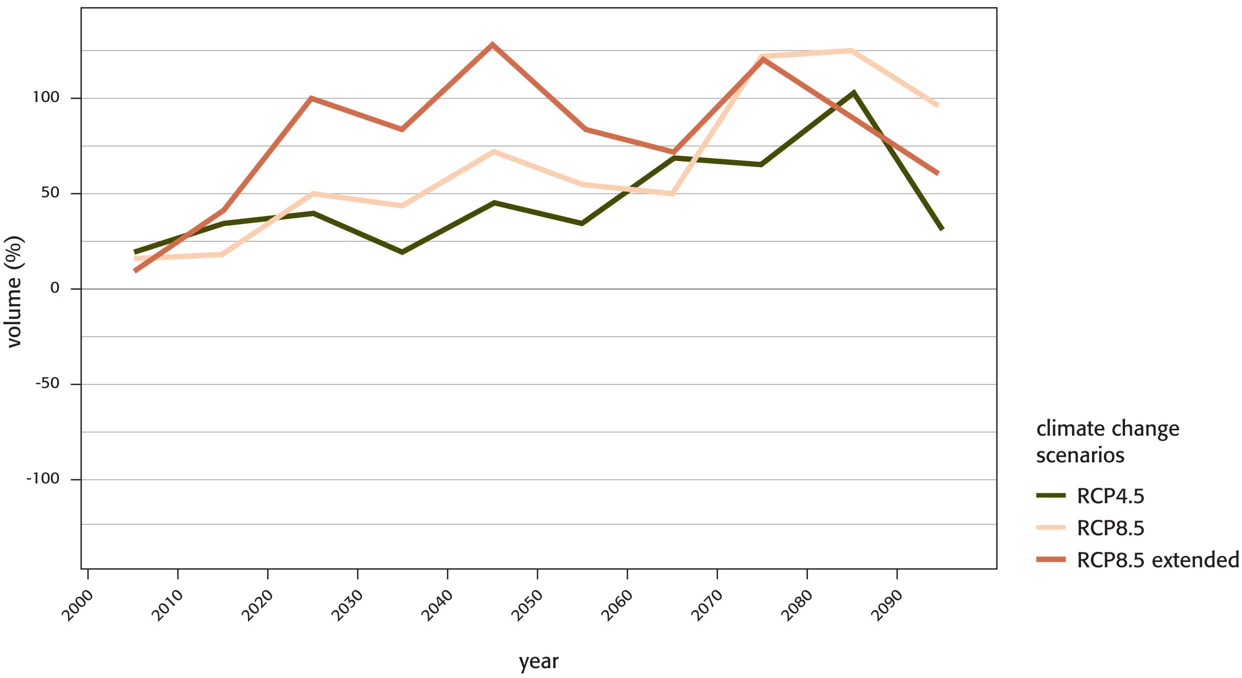
Source: Lexer et al., 2022

If current forest management continued under the three climate change scenarios, the response in terms of gross productivity would vary across altitudinal zones. Above 800 m, productivity would increase under RCP 4.5 and even slightly under RCP 8.5. However, the extreme scenario that is RCP 8.5e would result in a dramatic decrease in gross productivity from 2050 onward. The RCP 4.5 climate change scenario would have relatively minor impacts on gross productivity, but a significant portion of production would be lost due to tree mortality from disturbances.

Salvage harvests after spruce bark beetle infestation would increase in all (moderate to severe) climate change scenarios (see Figure 10). However, the timing and extent of this increase would vary depending on the climate change signal and the depletion of vulnerable spruce forests over time. In particular, the more extreme climate change scenario RCP 8.5 would not affect forests at higher altitudes to a substantial degree, due to their rather limited occurrence in most Central European countries.

Figure 10

Relative changes in salvage harvests due to spruce bark beetle in Central European forests under three climate change scenarios compared to historical climate, assuming continuation of current management



Source: Lexer et al., 2022

Forest owners are likely to adapt forest management to mitigate these impacts, but the extent and specific alternatives are challenging to estimate. Therefore, several adaptive forest management scenarios were analysed.

Adaptive forest management usually involves replacing productive coniferous and broadleaved species with generally less productive but more drought- and heat-tolerant broadleaves. As the future climate becomes more extreme, adaptive management approaches could reduce losses, stabilise production and stocks, and outperform current management practices. The introduction of non-native species, such as Douglas fir, could further enhance the effectiveness of climate adaptation strategies from a wood production-oriented forestry perspective. For example, under severe climate change conditions, adaptive management would increase harvested volume by 10–18 million m3 ob. per annum compared to the continuation of current practices. Additionally, over the long term, adaptive management would reduce – by up to 50% – losses in standing stocks that would occur with current management.

Wood damaged by bark beetle infestation can be reduced by two active forest management approaches: reducing the proportion of climatically vulnerable spruce to minimise the absolute amount of damaged wood, and mixing tree species to reduce the likelihood and intensity of damage.

Table 6 shows the mid- to long-term reduction of spruce harvest volume under the different adaptive forest management and climate change scenarios, compared to historical climate and current management practice.

Table 6

Differences in Norway spruce harvest volume in Central Europe as a function of adaptive management scenarios (AMS) and climate conditions related to harvests under current management in mill. m3 ob per annum

	2000–2050			2050–2100		
	RCP4.5	RCP8.5	RCP8.5e	RCP4.5	RCP8.5	RCP8.5e
AMS1	-2.50	-1.51	-0.65	-20.95	-22.60	-13.68
AMS2	-2.44	-2.15	-1.95	-21.50	-22.19	-12.72
AMS3	-3.27	-2.82	-2.38	-23.11	-24.02	-14.21
AMS4	-2.06	-1.49	-1.09	-20.42	-21.48	-12.46
AMS5	-1.38	-0.99	-0.72	-13.67	-14.38	-8.34
AMS6	5.27	4.90	4.33	-0.72	0.95	-1.35

* Scenarios shaded in green are most likely

Source: Lexer et al., 2022

2.4.3 Examples of modelled forest growth under future climate change in European countries

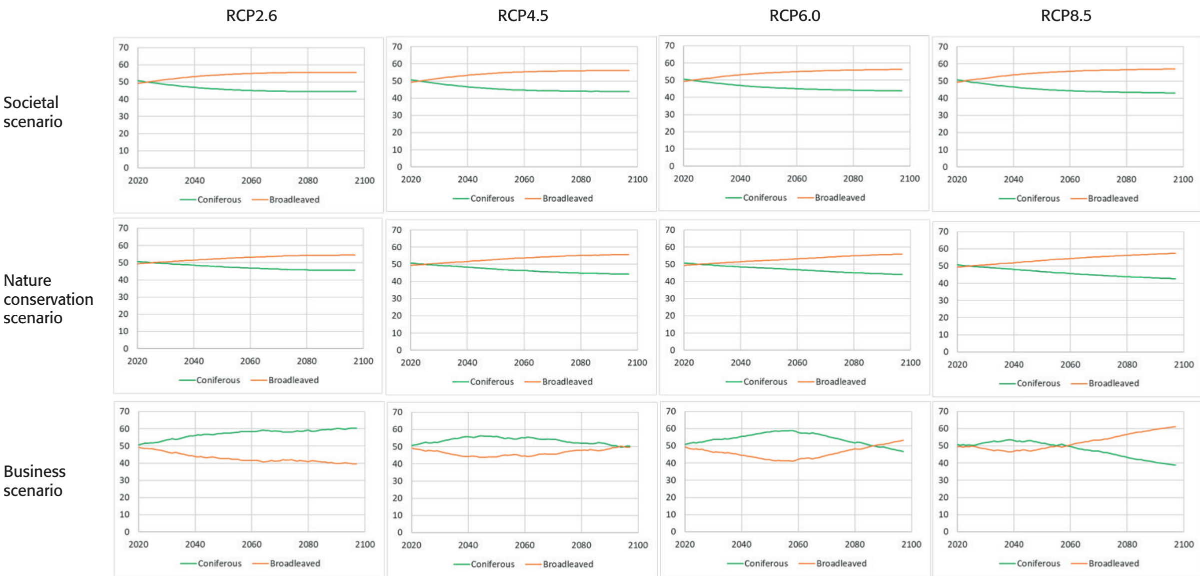
In the BioKraft project for the German Federal Ministry for Digital and Transport (BMDV), three distinct forest management scenarios (societal, nature conservation and business scenario) were defined in alignment with the German forest development and wood production scenarios. All three scenarios were evaluated in relation to the four different climate change scenarios RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 (see Box 1). The climate impact on German and European forests was modelled and analysed with IIASA's Global Forest Model G4M (IIASA, 2021). This model simulates forest development in terms of stand stock, harvest quantities and tree species proportions up to the year 2100 under four different climate change scenarios (RCP 2.6, 4.5, 6.0 and 8.5, using climate data from Inter-Sectoral Impact Model Intercomparison Project Phase 2b; HadGEM2-ES).

In the societal and nature conservation scenarios, there is an assumed policy and management priority favouring deciduous over coniferous trees (50% and 60% respectively) and strong demand for setting aside forest areas (1.3 million and 4.3 million ha, respectively). In contrast, the business scenario prioritises the most productive and economically beneficial tree species, with only 1.1 million ha to be set aside.

Regarding the transition toward climate-adapted forests with a higher proportion of broadleaved species in German forests, Figure 11 shows the area fraction of coniferous and broadleaved species under different climate and management scenarios from 2020 to 2100. It is assumed that during regeneration, deciduous tree species are promoted in the societal and nature conservation scenarios, which would lead to an increase in their proportion. This transformation would occur faster in the societal than in the nature conservation scenario due to the rotation period, resulting in a larger area undergoing regeneration with broadleaved species within the same period. In contrast, the business scenario prioritises regeneration of the most productive and economically beneficial species at the time, which are currently conifers. However, except for climate scenario RCP 2.6, the relationship between coniferous and deciduous species would change over time, with an increasing use of deciduous trees. In RCP 8.5, the point in time at which broadleaved species would dominate over coniferous is reached quite early, whereas the highest proportion of broadleaved species would be achieved by the end of the century due to the shorter rotation period compared to the other scenarios. Where there are rapidly changing environmental conditions and urgent forest transition needs favouring a greater share of broadleaved species, it can be advantageous in the assessed region to manage forests more intensively so as to increase the share of broadleaved trees, rather than to extend rotation periods and set aside large forest areas.

Figure 11

Forest composition (% of coniferous and broadleaved species) under three management scenarios for Germany by climate pathway; coniferous trees are represented in green, while broadleaved trees are shown in red



Source: IIASA, BioKraft, 2022

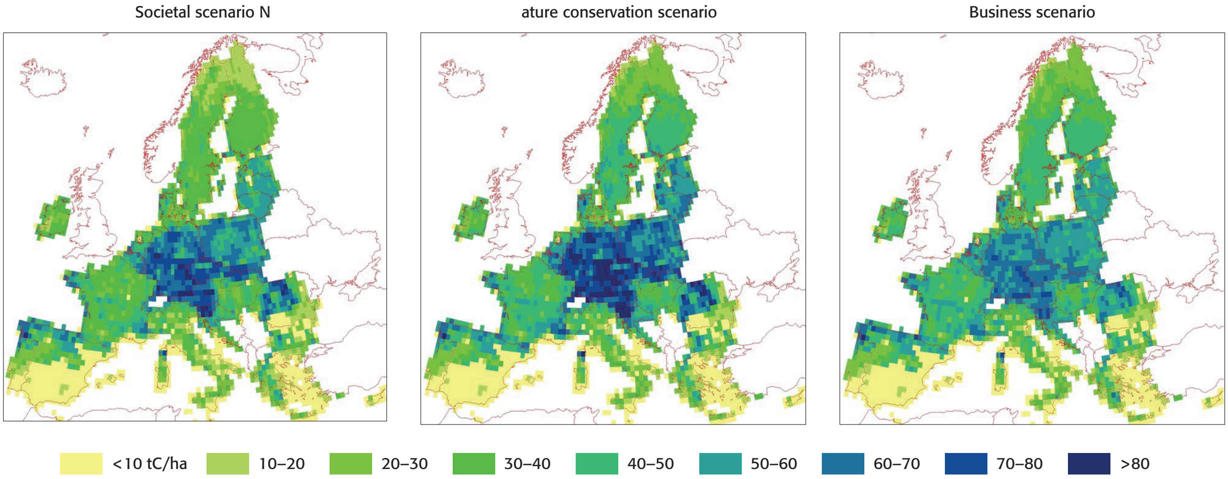
Figure 12 illustrates the development of carbon stock in stem wood (standing forests) in the European context under different management scenarios. It is projected that the stock level would be relatively high in Germany and Eastern Europe, reaching its peak under the nature conservation scenario and its lowest point under the business scenario. These high levels of carbon stocks in standing forests are likely to also be a result of relatively old forests being managed with longer rotation periods – compared, for instance, to the Nordic countries, where there is less growing stock in what are mostly younger forests.

In summary, this example indicates that forests play a crucial role in sequestering substantial amounts of carbon and offering a diverse array of ecosystem services. The management approach can have a major influence on the development of a forest and hence of the carbon stocks in standing forests. The conservation scenario would yield an increase in standing stock under moderate climate change scenarios (RCP 2.6, RCP 4.5), provided that more severe forest damage can be avoided. And the business scenario would lead to an increase in wood harvest volume which would reduce the carbon stocks in standing forests, but may contribute to an increase in the carbon stocks in harvested wood products (HWPs). The business scenario keeps the forest younger and makes it possible to more rapidly adapt the composition of tree species (e.g. from coniferous to mixed or broadleaves) to the new site conditions (e.g. hotter and drier climate) in the short term.

In conclusion, assumptions and calculations from the BioKraft project suggest that, in all three forest management scenarios, stock levels are projected to significantly decrease towards the end of the century. Assuming the continuation of present forest composition, forest types, and conventional management regimes, then climate

Figure 12

Total carbon stock in stem wood in Europe (tC/ha) in 2030 under RCP2.6 climate scenario



Source: IIASA, BioKraft, 2022

change effects – including increased risk of disturbances – will have substantial impacts on forest ecosystems in Europe. These projected future developments require fast and immediate action to promote and enable the transition of forests towards climate-fit ecosystems and adapt forest management systems.

Another example is presented by Gregor et al. (2022) looking at optimisation of forest management in Europe in a state of climate change uncertainty. This study simulated six forest management alternatives, including setting aside forests and transforming forests into mixed broadleaved or coniferous forests across Europe under four climate change scenarios. Seven indicators for key forest ecosystem services were projected, including wood harvests, climate change mitigation, regional cooling, soil water availability, deadwood and species diversity. For this, no specific quantitative targets – such as wood removals, carbon sequestration or deadwood/*old-growth forests* – were set. Instead, the societal and policy goals of wood production, climate change mitigation and biodiversity conservation (see Chapter 3) were represented by weighting forest ecosystem services. When equal weighting was given to each indicator, a total of 30% of the forest area was set aside, 34% of forests were transformed into mixed broadleaved forests and 11% into coniferous forests. Interestingly, the proportion of unmanaged forests did not differ significantly between the bioclimatic regions in Europe. If the weighting for wood harvests was doubled relative to the other indicators, the share of unmanaged forests was reduced to 18%. This analysis of projected trade-offs between the provision of different forest ecosystem services demonstrates the sensitivity of forest management outcomes to societal and policy preferences.

2.5 State-of-the-art knowledge on forest modelling

There are two general approaches to modelling forest vegetation: static and dynamic ones. Static modelling approaches simulate the occurrence of species or vegetation types in geographical or bioclimatic space as a function of the environment (i.e. 'distribution' models). Dynamic modelling approaches describe the development of tree populations and/or ecosystem processes (e.g. gross primary production, respiration and transpiration over time) as a function of management and the environment.

2.5.1 Distribution models

The conceptual approach of distribution models dates back to Alexander von Humboldt and his attempts to describe zones where certain species and species assemblages occur based on descriptive attributes such as geographic location, altitude and climate. Later, in the 1960s, this approach was then developed further by Holdridge (in the 'life zone' concept). This approach rapidly gained in importance, as discussion about global climate change required tools to estimate potential impacts on vegetation. Correlative relationships between the presence/absence of a certain species assemblage (i.e. vegetation type) and predictive site descriptors, including climate parameters such as temperature and precipitation, were calibrated based on empirical data sets such as large-scale inventories to calculate the probability of occurrence under any given set of predictor variables. If climate change conditions were reflected by the climatic predictor variables, changes in occurrence probability were calculated and mapped as 'species distribution'. Due to the ease of calibration and application in predictive mode, this approach gained enormous popularity in the 1990s and 2000s (Thuiller et al., 2008; Zimmermann et al., 2010).

However, there has also been substantial criticism of the use of such models in predictive mode. A general issue was the debate about whether vegetation types (i.e. assemblages) are useful modelling entities in the light of paleo-vegetation science findings that current natural vegetation types have been formed only recently in the course of re-immigration of species after the last glaciation in Central Europe. The solution was to model the occurrence of species instead. Another assumption of the distribution model approach is that it is possible to capture the fundamental niche of a species from observational data (i.e. presence and absence in a landscape). Typically, provenance-specific differences regarding both tolerance towards climate and requirements are neglected in large-scale model calibration attempts. As a consequence, predicted impacts of climate change may lead to erroneous conclusions (Araújo and New, 2007; Boiffin et al., 2017; Valladares et al., 2014). Transforming the likelihood of occurrence into a 'species suitability' rating is another challenge under this approach. Examples of this approach are Hanewinkel et al. (2013), Kölling et al. (2009), and Zimmermann and Bugmann (2008).

2.5.2 Dynamic climate-sensitive forest models

The potential distribution of tree species or tree species assemblages (i.e. natural forest types) under future climatic conditions may be helpful in indirectly indicating climate change impacts and highlighting adaptation needs in forest management. However, if the response of forest ecosystems to a changing climate over time is to be projected, tree demography must play a key role. Tree growth is fundamental from the perspective of biomass production; however, tree mortality largely shapes forest structure and is pivotal for ecosystem biogeochemistry. Tree establishment processes are crucial in determining ecosystem resilience after disturbances (Seidl and Turner, 2022). Furthermore, tree establishment is a key process in explaining range shifts. Thus, models that consider demographic processes in addition to growth are needed to study the long-term interactions between forests, climate and management.

Beginning in the 1960s, the first dynamic forest models using individual trees as modelling entities were developed in the United States (US). They were capable of mimicking tree population dynamics (Newnham, 1964). Two general modelling approaches were developed: (i) empirical models driven by research into forest growth and yield, which used statistical relationships between tree attributes such as diameter and tree height to model the growth and mortality of individual trees (Hasenauer, 1994; Pretzsch, 1992; Stage, 1973; Sterba and Monserud, 1997; Wykoff et al., 1982); and (ii) 'gap' models which integrated growth, mortality and recruitment of trees to study the successional dynamics of forest ecosystems as a function of resources such as light and nutrients. These models also included the effect of climate via temperature and water availability (Botkin et al., 1972; Bugmann, 1994; Kienast, 1987; Lexer and Hönninger, 2001; Shugart, 1984). Another approach focused on net primary-production processes driven by temperature and water availability but neglected tree population structure (Running and Coughlan, 1988). To study climate change impacts on forests and to consider the effects of management, tree population models were developed to include climate variables as model drivers. Empirical tree-based models were thus enhanced by climatic predictors (Fabrika and Ďurský, 2005), while gap models were gradually extended with process-based formulations of growth and tree death (Huth and Ditzer, 2000; Seidl et al., 2005). Whereas the typical spatial scale of these models was the 'forest stand' (i.e. a homogeneous tree population at the local scale), landscape models extended the spatial dimension to thousands of hectares, enabling the specific simulation of large-scale disturbance regimes (Mladenoff, 2004; Seidl et al., 2012). While a wealth of experience is now available regarding the modelling of tree growth and tree mortality, tree regeneration – and, unexpectedly, forest management practices – require more attention to overcome limitations and uncertainties.

In summary, a suite of static and dynamic model types is available to estimate climate change impacts. Acknowledging the limitations and potentials of the specific model types is pivotal to avoiding misleading conclusions from model applications.

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3

Chapter 3

Policy factors

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SUMMARY AND KEY MESSAGES

Global, European and national policy and legal frameworks – including (but not limited to) public policy regulations, public funding, and non-state market-driven governance mechanisms – are likely to remain major factors affecting future forest management. And, as such, they can be expected to shape the supply of wood and the use of forest-derived bioenergy in the future. Essentially, the European multisectoral and multilevel policy and institutional framework is likely to remain marked by trade-offs and fragmentation, because the different policy objectives and instruments are partly incoherent, both within and between the specific global, pan-European, EU and national forest policies.

At the global and pan-European levels – involving the UN Forum on Forests (UNFF) and FOREST EUROPE (formerly the Ministerial Conference on the Protection of Forests in Europe) – non-legally binding guidelines, criteria, and indicators for *sustainable forest management* (SFM), with emphasis on multiple-use forests, have been developed. These SFM-supportive, 'soft law' policies have been implemented with unclear effects on forest management.

Several legally binding and non-legally binding EU regulatory policies on nature protection and biodiversity conservation (e.g. EU Biodiversity to 2030, EU Forest Strategy to 2030, the EU Habitats and Birds Directives, the EU Nature Restoration Draft Law, EU Deforestation Regulation (EUDR)) have been developed to push for an environmental transformation of national forest policies and management. These include a policy and management prioritising forest 'set asides', conservation of old-growth forests and forests in protected areas (within and outside Natura 2000, the European network of protected areas), *close-to-nature* forest management, avoidance of clearcutting, and promoting biodiversity-friendly afforestation and reforestation. Closely aligned EU climate policies (e.g. European Green Deal, the 'Fit for 55' Package, and the EU's Land Use, Land Use Change, and Forestry (LULUCF) Regulation) have also been formulated to induce EU countries to support forest biodiversity conservation, carbon sequestration in standing and old-growth forests and, to some extent, in harvested wood products (HWPs). In all EU regions, the results of these environmental policies on future forest management are likely to translate into restrictions on forest areas available for wood supply, and a reduction of available *softwood* from coniferous species due to clearcutting bans or avoidance in monoculture forests, and stronger support of the close-to-nature forest management approach, which favours *hardwood* species over softwood species in mixed forests.

Another set of legally binding and non-legally binding EU policies offering subsidies and/or regulating markets (e.g. the EU Renewable Energy Directive, EU Bioeconomy Strategy, EU Rural Development Regulation, EU Timber Regulation) have been developed to promote wood use for construction and/or energy, as well as for carbon storage in HWPs, and for *bioeconomy* purposes. This set of policies may create conflicts with the set of policies mentioned in the previous paragraph.

At the national level, forest management remains shaped by a diverse set of priorities in forest and forest-related policies and legal frameworks. Distinct regional differences include policy priorities for bioenergy, carbon forestry and sustained-yield forestry (Northern and Eastern Europe), multipurpose forestry (Central Europe), and carbon forest management and forest biodiversity conservation (Western and Southern Europe). Important trade-offs between prioritisation of wood production and prioritisation of forest conservation arise from the different EU and national policies, and between and within the different policy priorities of the European countries. These vertical and horizontal policy trade-offs are likely to lead to legal uncertainty and conflicting policy framework conditions influencing future wood supply.

3.1 Global level

There is no single institutional focus, and no coherent policy framework at the global level on how to sustainably manage forests (Arts et al., 2010). As at EU level (see below), global forest-related policy issues (e.g. deforestation, forest degradation, biodiversity loss, climate change, illegal logging) are mainly governed through legally binding United Nations (UN) conventions on global environmental commons. This 'hard law' of multilateral environmental agreements mainly includes the UN Convention of Biological Diversity (CBD) and its post-2020 Kunming-Montreal Global Biodiversity Framework, as well as the UN Framework Convention on Climate Change (UNFCCC) and its implementation through the Paris Agreement. Their national implementation is expected to help achieve forest-specific policy goals of conservation and sustainable use of (forest) biodiversity as well as of climate mitigation and climate adaptation in the LULUCF sector. They should also help achieve the overarching UN Sustainable Development Goals (SDGs) formulated under the UN Global Sustainability Agenda 2030 (Begemann et al., 2021; Rayner et al., 2010).

Another set of global policies includes non-legally binding UN 'soft law' promoting SFM, including through criteria and indicators. Similar to the EU level, these policy objectives are furthered by the Non-Legally Binding Instrument on Forests and the UN Strategic Plan on Forests 2017–2030 formulated by the UNFF and the International Arrangement on Forests (IAF). Economic and trade-focused international policies such as the International Tropical Timber Agreement (ITTA), and the transnational Forest Law Enforcement, Governance and Trade (FLEGT) initiatives, provide another important foundation for global action to secure the main policy objectives of the legal wood trade. Transnational public-private partnerships on reducing emissions from deforestation and forest degradation includes biodiversity and social safeguards (Reducing Emissions from Deforestation and Forest Degradation (REDD+)) augment the set of policies in the economic incentive-based global forest policy mix. Non-state market driven governance mechanisms such as the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) have also been developed and implemented to foster private certification standards of sustainable forest management (Berning et al., 2023; Glück et al., 2005; Rayner et al., 2010).

3.2 Pan-European level

Like the UNFF process, the countries working together within the Ministerial Conference on the Protection of Forests in Europe, later renamed FOREST EUROPE, have manged to define common visions, goals and SFM criteria and indicators in non-legally binding resolutions (Pülzl et al., 2013). According to FOREST EUROPE signatory countries reports, national public policies using regulatory instruments play an essential role, *inter alia* through national forest laws and domestic implementation of the EU's Nature Directives (Birds and Habitats Directives). The EU Nature Directives were described as being the most important triggers for policy and legal changes for forest management in European countries. As reported by the countries, specific references to the implementation of global hard-law and soft-law commitments in relation to the CBD, the UNFCCC and the UNFF are scarce (Rametsteiner, 2015).

Public grants or subsidies are the most commonly reported financial instruments employed, mostly for forest biodiversity, i.e. protected areas. Financial support is also directed towards forest inventories, management planning, and the protection of soil and water. Informational instruments, such as monitoring, education, and advisory services are also widely applied across all reporting countries to integrate environmental objectives into sustainable forest management. Data from 17 signatory countries in Europe about their total allocations of public expenditure across the six criteria for SFM (Rametsteiner, 2015) indicates that, on average, around 10% of all funds are allocated to each of the following functions of forests: health and vitality, biodiversity and socioeconomic.

In terms of strategic importance, the FOREST EUROPE process has been used by many countries to counteract the growing influence of EU environmental policies on national forest policy and forest management. However, the idea of entering into a pan-European legally binding agreement on SFM could not materialise due to institutional conflicts among the participating countries (Edwards and Kleinschmit, 2013).

3.3 European Union level

A review of state-of-the art policy and legal research reveals that the regulation of forest management issues in the EU and its Member States is subject to a complex EU multilevel policy and legal framework.

On the one hand, the treaties establishing the EU make no legal provision for a specific common EU forestry policy. As a result, non-binding EU forest strategies and action plans that contain well-intended objectives on sustainable forest management have been agreed between the EU institutions and the Member States. Attempts to establish an EU-wide specific forest policy by (environmentally inclined) EU institutions have met with strong resistance and opposition, particularly from forest-rich Member States with economically important forest-based industries, influential forest owner associations, public forestry enterprises and public forestry authorities (Onida, 2020). Consequently, the control of forest management policy and legislation in Europe has seemingly remained under the sovereignty of each Member State in line with the 'subsidiarity principle' (Pülzl et al., 2018).

On the other hand, however, regarded in legal terms and in a context of shared competencies, the EU has often made use of its decision-making and regulatory powers stipulated in the EU Treaties to establish a range of EU *forest-related* policies. This is demonstrated by the variety of other established EU policies and rules adopted over the years that relate directly or indirectly to forest management issues. These are founded on the basis of EU law on the environment, as well as that on other areas including agriculture and energy. The jurisprudence of the European Court of Justice, which is empowered to interpret EU primary and secondary law, shows also that responsibilities for forests do not legally rest with the Member States only (Onida, 2020; Pülzl et al., 2013).

3.3.1 EU and national (forest) biodiversity policy

At the EU level, a range of environmental forest policies based on hard law (regulations, directives) or soft law (strategies, guidelines) have been developed. They will very probably influence forest management and wood supply over the decades to come (see Table 7).

In 2019, the newly appointed EU Commission adopted a Communication on the European Green Deal, whereby forest protection in the EU is deemed a political priority in pursuing the new EU policy objectives, specifically climate policy (55% greenhouse gas emission reduction by 2030) and biodiversity policy (conservation status for 30% of the EU land area, incl. 10% subject to strict designations by 2030). The European Green Deal (in conjunction with the EU Climate Law, the new EU Biodiversity Strategy to 2030 and the new EU Forest Strategy to 2030) calls for a transformative process of change aiming at tackling the biodiversity and climate crisis in an integrated way. These EU policies recognise that forest ecosystems are under increasing pressure and call for action to improve the quantity and quality of forests, and for the EU and its Member States to achieve climate neutrality (net zero) by 2050 and a healthy environment by 2030 (EC, 2019).

Under the new European Green Deal Policy, the new EU Biodiversity Strategy to 2030, adopted in May 2020, sets out three key objectives that need to be achieved by 2030: (i) to legally protect at least 30% of the EU land area (a 4% increase over the present day) and integrate ecological corridors, as part of a true Trans-European Nature Network; (ii) to strictly protect at least a third of the EU's areas under protected status, representing 10% of EU land, including all remaining EU primary and old-growth forests; and to (iii) effectively manage all protected areas, defining clear conservation objectives and measures, and monitoring them appropriately.

The new EU Biodiversity Strategy to 2030 contains a chapter about actions on forests, requiring the strict protection of all remaining EU primary and old-growth forests and increasing the forested area by planting at least three billion additional trees in the EU by 2030. It also aims at increasing the share of forest areas covered by management plans, and at developing guidelines on biodiversity-friendly practices on afforestation and closer-to-nature forestry. Furthermore, to counter the pressure of the increased demand on forests for biomass, the use of whole trees for energy production should be minimised, and bioenergy should focus primarily on wood waste and residues. Lastly, and importantly, an EU Nature Restoration Plan will set legally binding conservation targets to restore degraded terrestrial (forest) ecosystems, landscapes and forest-related water bodies, to enhance sustainable management and resilience. The Plan requires measures to increase the quantity, quality and resilience of managed and protected forests in the EU-27. This refers to restoration measures such as biodiversity-friendly afforestation, reforestation and tree planting, closer-to-nature-forest management as a biodiversity-friendly practice, integration of biodiversity and restoration objectives in management plans of forest owners. The Plan also aims at creating jobs, reconciling economic activities (e.g. forestry) and biodiversity objectives, and ensuring long-term productivity and value of the natural capital (EC, 2020).

As an initiative of the European Green Deal, and by building on the EU Biodiversity Strategy for

Biodiversity policies influence forest management in the EU
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2030, the Commission adopted a new EU Forest Strategy to 2030 (EU-FES). The main objectives of the EU-FES are: effective afforestation, forest preservation and restoration in Europe; contributing to an increase in carbon dioxide (CO2) absorption; reducing the incidence and extent of forest fires; and promoting the sustainability of the forest-based bioeconomy while fully respecting ecological principles conducive to biodiversity. It also aims to strictly and effectively protect all primary and old-growth forests in the EU. Most importantly, the EU-FES demands that clearcutting practices in EU countries should be approached with caution, generally avoided and used only in duly justified cases – for example, when necessary for environmental or ecosystem health reasons – and should include environmental and ecosystem concerns (EC, 2021).

In June 2022, the EU Commission presented a legislative proposal for an EU Nature Restoration Law. If and when adopted, this Law aims to (i.) restore at least 20% of land and sea by 2030, and all ecosystems in need of restoration by 2050; (ii.) request EU Member States to develop National Restoration Plans taking account of national circumstances; (iii.) build on EU nature laws, focusing on all natural habitats, and not just those protected under the EU Birds and Habitats Directives (Natura 2000); and (iv) demonstrate EU leadership in protecting and restoring nature, and set the bar for global action ahead of the Biodiversity COP15 (15th meeting of the Conference of the Parties) of the CBD (EC, 2022). As regards restoration of forest ecosystems, the EU Nature Restoration Law (June 2022 draft) will request EU Member States to implement restoration measures necessary to enhance biodiversity of forest ecosystems, in addition to Natura 2000 forest areas. Member States shall also be required to achieve improvements in forest ecosystems – at national level and under each of a set of indicators – by 2030, and every three years thereafter, until satisfactory levels are attained. This set of indicators includes (a) standing deadwood; (b) lying deadwood; (c) share of forest with uneven-aged structure; (d) forest connectivity; (e) common forest bird index; and (f) stock of organic carbon (EC, 2022).

In short, the European Green Deal, the EU Habitats and Birds Directives, the new EU Nature Restoration (draft) Law, the EU Biodiversity Strategy to 2030 and the EU Forest Strategy to 2030 require the EU countries (among other goals) to restore and conserve forest biodiversity, to increase the share of forest protected areas, to effectively protect old-growth forests and increase deadwood in all forests, and to improve conservation of Natura 2000 forest sites. They also request countries to store more carbon in standing forests, avoid clearcutting and foster close-to-nature forest management and biodiversity-friendly reforestation/afforestation in the EU-27 and beyond.

Table 7

Overview of EU forest-related biodiversity and climate policies and policy targets

EU ENVIRONMENTAL FOREST POLICY TARGETS	EU POLICY FRAMEWORK
Expanding forest protection and restoration by protecting at least 30% of the (forest) land in the EU by 2030, of which at least 10% should be strictly protected areas of high biodiversity and climate value (forest set-asides), as well as by strict protection of remaining primary and old-growth forests (currently below 5%). Better conservation and restoration management in the EU-wide network of Natura 2000 sites (50% of which are in forests). Increase in the quantity, quality and resilience of managed forests and protected forests in the EU-27 by means of biodiversity-friendly afforestation, reforestation and tree planting, closer-to-nature-forest management, and integration of biodiversity and restoration objectives in forest owners' forest management plans. Restoration of degraded terrestrial (forest) ecosystems, landscapes and forest-related water bodies (due to climate change impacts and/or unsustainable intensive forestry practices, e.g. clearcutting, monocultures). Sustaining biodiversity and ecosystem services while ensuring sustainable forest management. Creating jobs, reconciling economic activities (e.g. forestry) and biodiversity objectives, and ensuring long-term productivity and value of the natural capital.	European Green Deal (climate and biodiversity policy focus) New EU Biodiversity Strategy to 2030 New EU Forest Strategy to 2030 EU Birds and Habitats Directives (Natura 2000) EU Nature Restoration (Draft) Law (2022) National forestry, nature conservation, and climate laws, bylaws and strategies

Source: Produced by Sotirov, 2023

In conclusion, the EU (forest) biodiversity policy objectives, if and when implemented by the countries concerned, are likely to have important impacts on the *forest sector* resulting in reduced market availability – in terms of both current quantity and current specific qualities – of wood (in particular softwood) from EU forests. They are also very likely to further increase the dependence of the EU-27 on wood (softwood) imports from Eastern Europe (e.g. Russia, Ukraine, Western Balkans) and tropical regions (South-East Asia, Central Africa, South America), if the current and future wood supply gaps are to be addressed.

3.3.2 EU climate forest policy

Recently, the Commission further developed an overarching EU climate neutrality (net-zero) policy with the adoption of the European Green Deal, its Action Plan and 2030 Climate Target Plan. This EU climate policy, now supported by the Member States, aims to cut greenhouse gas (GHG) emissions by at least 55% by 2030, and to adopt a legally binding commitment to make the EU-27 climate neutral by 2050. In this policy, the Commission and Member States recognise the key role of forests and forestry in achieving climate goals. Under the new EU climate law, Member States are required to ensure that accounted GHG emissions from the LULUCF sector are balanced by at least an equivalent accounted removal of CO2 from the atmosphere, known as the 'no debt rule'. In line with this, the EU LULUCF Regulation (Regulation 2018/841) on inclusion of GHG emissions and removals from LULUCF in the 2030 Climate and Energy Framework was adopted by the Council and the Parliament in 2018 (EP and CEU, 2018).

The EU LULUCF Regulation establishes a legally binding EU environmental regulatory policy for accounting of, and for monitoring how Member States deal with, GHG emissions and removals from management practices in their forests during the compliance period 2021–2030 (Art. 8). In October 2020, the Commission amended the existing EU LULUCF Regulation with a delegated act setting forest reference levels (FRLs) that each country must apply between 2021 and 2025. FRLs are a projection of the net GHG emissions from managed forest land in 2021–2030, assuming that forest management practices had continued in similar fashion to those in the reference period 2000–2009. A decrease in sink relative to the reference level is included as emissions for accounting purposes. Specific national circumstances and practices, such as lower harvest intensity than usual or ageing forests during the reference period, should be taken into account (Recital 23, Art 8.4). In this way, FRLs provide a means to account for the impact of policy and forest management changes on emissions and removals from forests, while factoring out the impact of age-related dynamics in forests (EC et al., 2020; Grassi and Pilli, 2017).

The EU LULUCF Regulation seeks to support forest owners and forest industries by achieving greater 'visibility' for the climate benefits of harvested wood products which store carbon from the atmosphere for long periods. FRLs and national scope for flexibility (e.g. under the Effort Sharing Decision, countries are allowed to use a limited amount of credits (280 Mt CO2) generated in the LULUCF sector to offset emissions; countries may also increase wood logging by 10% but, given the requirement to compensate within other sectors at EU level, are expected to help farmers develop climate-smart agricultural practices and support forest managers through greater visibility for the climate benefits of wood products. These products can store carbon sequestered from the atmosphere and substitute for emission-intensive materials (EC et al., 2020; Grassi and Pilli, 2017).

National-level implementation of the LULUCF Regulation is, however, still a work in progress, and is proving to be challenging due to complex technical rules and to recent practices involving enhanced wood removal intensity, including larger clearcuts that should be reducing forest sinks in (most of) the EU countries (Ceccherini et al., 2020). The LULUCF Regulation recognises harvest intensity as "a core element of sustainable management practice" (Article 8(5), but does not determine in detail how it should be defined. According to a recent EU study (EC et al., 2020), the majority of Member States were found to define forest management activities during the reference period in terms of rotation lengths, age or size thresholds, target species or cohort, and determination of wood harvest intensity. More importantly, this Joint Research Centre (JRC) study has ascertained that wood harvest volumes in the FRLs are projected to increase in most Member States, when compared to the reference period. The only exceptions are Belgium, Greece, the Netherlands and the United Kingdom, where the total harvest is projected to be slightly lower in the compliance period 2021–2025, compared to the reference period 2000–2009. The FRLs project the total wood harvests in the EU to increase by approximately 16%, from around 510 million cubic metres (Mm3) in the reference period 2000–2009 to about 600 Mm3 for the compliance period 2021–2025. The differences between Member States are notable, ranging from more than 50% larger harvests in the FRL than in the reference period projected by Denmark, Croatia and Ireland, to a slight decrease projected by Belgium, Greece, the Netherlands and the UK between the reference period and the FRL. In numerical terms, the sum of the Member States' FRLs (EU-28) in the delegated act is a projected sink of -337 Mt CO2 per annum for the period 2021–2025 (EC et al., 2020). This projection is about 18% lower than the sink of -413 Mt CO2 per annum reported by the EU 2019 GHG inventory on managed forest land for the period 2000–2009 (EEA, 2019). This EU net forestry sink is smaller in 2021–2025 or 2026–2030 than during the historical reference period 2000–2009. If implemented this way, forestry practices might lead to a net carbon loss that will be at odds with the EU goals of maintaining or enhancing the carbon stored in standing forests, or helping conserve forest biodiversity (EC et al., 2020; EEA, 2019). They will allow increased wood harvesting equivalent to 80 million tonnes of CO2 to be removed from forests and captured in harvested wood products and/or combusted in woody bioenergy. This might help the forest sector contribute to meeting the EU's and national climate mitigation goals (Nabuurs et al., 2018), but it would be likely to jeopardise the environmental integrity of the EU 2030 climate targets for 2030 and 2050 (FERN, 2018; FERN et al., 2021).

In conclusion, increasing wood harvesting projections and practices in the future would make it hard to meet the carbon sink targets of the (revised) EU LULUCF Regulation and the EU's 'Fit for 55' climate policy objectives. The EU's LULUCF Regulation permits carbon loss in standing forests at the expense of carbon gains in harvested wood products. Subject to national legal restrictions and forest management practices, countries are generally not discouraged by the EU LULUCF Regulation to increase harvesting in forests (e.g. by clearcutting). Intensive forestry in pristine or old-growth forests is not discouraged under the EU LULUCF Regulation either, even if these forests are known to be important not only as long-term carbon stocks and ongoing carbon sinks, but also for their biodiversity and recreational value (Global Scientists, 2020).

3.3.3 EU and national renewable energy policies

There is another set of EU forest-related policies that works with a mixture of regulatory and economic tools. It mainly consists of the EU's Renewable Energy Policy, which is based on the EU's Renewable Energy Directive (Renewable Energy Directive (Directive 2009/28/EC – RED I) and its revision (called the Revised Renewable Energy Directive (Directive 2018/2001 – RED II). As part of the Clean Energy for All Europeans package, RED II establishes a common EU policy and financial support framework for the use of energy from renewable sources, including from forest biomass, in order to limit GHG emissions caused by the EU and its Member States (Directive 2009/28/EC, Directive 2018/2001). Member States have, among other requirements, to fulfil binding targets to increase the share of renewable energy, including from woody biomass, in their energy consumption; they can avail themselves of financial support in the form of EU subsidies. The RED II establishes a legally binding 2030 renewable energy target for the EU of at least 32% of final energy consumption, with a clause allowing for a possible upwards revision by 2023. As part of the EU's most recent 'Fit for 55' package under the European Green Deal and EU Climate Law, the upcoming revisions of the revised RED II are intended to contribute to the EU's goal of reducing GHG emissions to 55% of 1990 levels by 2030 (Camia et al., 2021).

Forests are seen as the main source of biomass for energy and wood production in the EU-27. More robust accounting rules for forest management under the LULUCF Regulation (see above) are expected to provide a solid basis for implementation of the RED II after 2020. This should address earlier broad criticism that GHG emissions from biomass in energy production were not accounted for under the previous EU RED I (Sotirov et al., 2021).

According to the proposed changes of the RED II, Member States would be no longer allowed to grant financial support for the felling of 'high quality' roundwood, such as forest biomass from saw logs and veneer logs to produce bioenergy. As with the EU Timber Regulation (EUTR), the Commission would adopt a delegated act on how Member States should request economic operators (e.g. private and public forest owners, traders, bioenergy plants) to apply a risk-based approach to secure legal and sustainable production of bioenergy from woody biomass. The legality of harvesting operations should be secured when economic operators provide evidence (a) of the country of harvest and, where applicable, the sub-national region where the forest biomass was harvested, including the sourcing area; and (b) that the national or sub-national laws applicable to the area of harvest ensure compliance of harvesting with the due diligence system defined in Article 6 of the EU Timber Regulation (Camia et al., 2021; Wolfslehner et al., 2020).

Forest biomass sustainability criteria and risk mitigation measures in the existing RED would also be amended to request that wood harvesting be carried out in a manner that prevents negative impacts on soil quality and biodiversity, to avoid harvesting of stumps and roots, to avoid degradation of primary forests or their conversion to plantation forest, and to minimise (but not prohibit) large clearcuts and encourage on-site retention of deadwood. These criteria would also include legal safeguards to ensure forest regeneration by demonstrating that (1) the applicable laws require natural or artificial regeneration, or a combination of both, aiming at the establishment of a new forest in the same area and within at least five years after harvesting; and that (2) there is no biodiversity degradation in the regenerated forest area, including as an objective that primary forests and natural or semi-natural forests are not degraded to or replaced with plantation forests. Further safeguards are the effective protection of areas designated by international or national law, or by the relevant competent authority, for nature conservation purposes, including areas being defined as wetlands and peatlands. The act would request Member States to request that economic operators ensure that harvesting maintains or improves the forest's long-term production capacity. This includes ensuring that annual amounts of felled wood do not, on average, exceed net annual increment in the relevant sourcing area within the five-year period prior to the harvesting intervention, unless different amounts are duly justified in order to enhance the future production capacity of the forest; or because of 'salvage logging' in documented events involving forest pests, storms or other natural disturbances (Camia et al., 2021; Wolfslehner et al., 2020).

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In conclusion, the RED II revision advises against wood harvesting in primary forests but does not ban this intensive forestry practice altogether. Neither does it include a general legal prohibition or limitation of intensive forestry (e.g. clearcuts). Those who make decisions on policy and practices can use RED II to partly regulate intensive forestry (e.g. clearcutting) in the EU Member States as regards the aforementioned legality and sustainability criteria. At the same time, the push to meet the EU renewable energy targets with the attractive EU subsidies may result in changes to forest land use patterns and forest composition (e.g. incentives for landowners to choose fast-growing tree species, and to continue practising even-aged forestry with clearcutting in line with national laws) in order to satisfy industry demand for woody biomass, at least in some Member States (Wolfslehner et al., 2020).

3.3.4 EU and national bioeconomy policies

The European Commission (EC) launched a new EU Bioeconomy Strategy and Action Plan in 2012, aiming to ensure food security while paving the way for lower emissions and a resource-efficient and competitive society, all within the boundaries of sustainable use of renewable resources and environmental protection. The bioeconomy is considered a key component of smart and green growth in the EU, emphasising an economy that is based on the use of biomass resources instead of fossil fuels (EC, 2013). It is presented as an important aspect of the European economy and society in terms of creating opportunities in different sectors and expanding the output of bio-based products. Accordingly, the EU Bioeconomy Strategy outlines a cross-sectoral and interdisciplinary approach that addresses not only the environment and energy production, but also food supply and natural resource challenges at a general, overarching level (EC, 2013). The Strategy is perceived as representing a significant opportunity for forestry, particularly in relation to investments in research, innovation and skills.

The EU bioeconomy strategy was updated in 2018 with the policy aim of accelerating the deployment of a sustainable European bioeconomy, contributing towards the UN Sustainable Development Goals (SDGs), and helping to meet the objectives of the Paris Agreement. It also responds to new European policy priorities, such as the renewed Industrial Policy Strategy, the Circular Economy Action Plan, and the Communication on Accelerating Clean Energy Innovation, all of which highlight the importance of a sustainable, circular bioeconomy to achieve their objectives. A related action plan formulates 14 specific measures launched in 2019 (EC, 2018). No specific EU bioeconomy legislation exists. However, sectoral legislation, in many cases considerably older than the concept of the bioeconomy, has a major impact in the field (Aggestam et al., 2017).

Concerns have been raised by the scientific community about the lack of reference to the forest-based sector and forest landowners in the Bioeconomy Strategy (Hetemäki, 2014; Ollikainen, 2014). Despite the absence of representation, the forest-based sector is arguably instrumental for implementing the Strategy. Within a bioeconomy, and the wider green and circular economy, the forest sector interacts with energy and chemical industries. The most relevant interaction between the forest sector and the bioeconomy involves carbon sequestration and climate change mitigation (e.g. harvested wood products), bioenergy (e.g. substitution of carbon-intensive materials) as well as environmental protection and nature conservation (Mubareka et al., 2014). The EU Bioeconomy Strategy is in line with some of the key research findings which conclude that the 'climate' and 'energy' policy domains are significant factors for forest development. The EU Bioeconomy Strategy can, if properly implemented, enhance sustainable and green growth that is likely to benefit forest-based industries in the long term (Hetemäki, 2014). However, the implementation of the EU Bioeconomy Strategy by means of national strategies has been a protracted and incomplete process so far.

3.3.5 EU and national rural development policies

The EU Common Agricultural Policy (CAP), including its Rural Development pillar (Regulation No. 1305/2013), is a key EU expenditure policy that involves the greatest transfer of financial resources to Member States through the EU budget (approximately 40% of total EU funds being distributed through the CAP). The main policy objectives of the CAP and Rural Development Programmes for the period 2013–2020, and also during the transition period until 2022, are (i.) fostering the competitiveness of agriculture and forestry; (ii.) ensuring the sustainable management of natural resources and climate action; and (3) achieving balanced territorial development of rural economies and communities (ECA, 2021; EP and CEU, 2013).

Specific forestry support measures are included in Articles 21 to 26 and 34 of the EU Rural Development Regulation, and transposed into two rural-development measures. Under Measure 8, 'Investments in forest area development and improvement of the viability of forests', Member States can opt to (not) use EU subsidies for several (economic) forestry activities. Specified sub-measures include the following: 8.1. Support for afforestation/creation of woodland; 8.2. Support for establishment and maintenance of agroforestry systems; 8.3. Support for prevention of damage to forests from forest fires, natural disasters and catastrophic events; 8.4. Support for investments improving the resilience and environmental value of forest ecosystems; 8.5. Support for investments in forestry technologies and in processing, mobilising and marketing of forest products (EC, 2017; ECA, 2021; EP and CEU, 2013). For example, sub-measure 8.5 (referred to above) covers the costs of investments of private forest holders, forest-holder associations, municipalities or small and medium-sized enterprises (SMEs) to improve the economic value of forests, enhance forestry potential and contribute to adding value to forest products via the processing, mobilising and marketing of these products. Investments related to the use of wood as a raw material or as an energy source must be limited to operations prior to industrial processing (EC, 2017; EP and CEU, 2013).

Under Measure 15, 'Forest-environmental and climate services and forest conservation', socio-ecological aspects of sustainable forest management can be financially supported. They include payments for forest-environment and climate service commitments (M15.1), and payments for conservation of forest genetic resources (M15.2) (EC, 2017; ECA, 2021; EP and CEU, 2013). Financial support under measure 15.1 (as under sub-measure 8.4) can be granted to public and private forest holders, as well as other private-law and public bodies and their associations. In the case of state-owned forests, support may be granted only if the body managing such a forest is a private body or a municipality. This financial support is intended to cover all or parts of the additional costs and income foregone resulting from one (or more) forest-environment and climate commitments, going beyond the relevant mandatory requirements established by the national forestry act or other relevant national law. Those commitments may include a large range of actions, such as (1.) maintaining specific forest habitats and the conditions for natural forest regeneration with high diversity; (2.) restructuring that allows regeneration and broader species diversity in order to improve biodiversity and climate resilience, as well as maintenance of a diverse forest edge or second crown layer to preserve forest microclimate and to preserve the carbon content of the forest soil; (3.) environmental management for recreation; (4.) low-impact silviculture, e.g. protection of the forest soil and ensuring its development, soil-friendly harvesting, transporting and regeneration methods (continuous cover instead of clearcutting); (5.) habitat improvements, including the improvement of wildlife corridors, e.g. maintenance of micro-habitats, small open areas, and leaving behind decaying and dead trees for biodiversity reasons; (6.) leaving groups of trees after final felling, maintenance of mosaic-character forest structure, postponement of final felling to protect habitats, soil and water sources, preservation of wetland habitats, and repression of aggressively expanding non-indigenous tree and shrub species (EC, 2017; ECA, 2021; EP and CEU, 2013).

However, research shows that different policy factors related to implementation, particularly the short timeframe for planning and monitoring, prevents the use of these funding opportunities for biodiversity conservation (de Buren et al., 2016). Moreover, countries tend to prioritise competitiveness of the agricultural and forest sectors rather than biodiversity conservation in their allocation of the available resources (Geitzenauer et al., 2017). No data exists, however, to quantify the biodiversity effects of forest management practices supported by EU rural-development funds (EC, 2017). This situation results in a funding gap that is not closed sufficiently by national or alternative funding sources and existing funds. There are also problems in defining the baseline forest management requirements: for example, those above which compensation payments are calculated, making implementation even more difficult (EC, 2017). Hence, the effectiveness of EU rural- development funding to support forestry in integrating biodiversity conservation objectives remains a challenging task.

Many EU countries have chosen to use EU rural-development support measures to promote forest harvesting and/or primary-processing companies, thus taking the forest-based sector's scope for investment as the focal point for direct action. This is not the case in other EU countries with enormous *forest resources*, a very laissez-faire forest policy and a somewhat negative attitude towards EU interventions in national forest policy. There, forestry measures under EU rural development policy have been designed to not affect the competitiveness of the forest-based sector (e.g. M8.5 has a potential effect on competitiveness), and investments into technology to not distort the market balance (EC, 2017; Geitzenauer et al., 2017).

Subsidies used through the forestry measures under the CAP and Rural Development funds in the previous programming period (2007–2013) were instrumental in stimulating forest-based industries. EU funds supported forestry actions aimed at increasing forested areas and wood resources by means, for example, of plantations of economically productive (fast-growing) tree species, building of forest roads, mechanisation of wood harvesting, and modernisation of wood processing. At the same time, Member States only used 13% of rural-development funding for forest-environment payments and 16% for Natura 2000 payments in forests during this period. This reveals an imbalance between rural-development and environmental policy goals in domestic implementation of the forestry measures under the EU Rural Development Policy. Table 8 further illustrates that the implementation of rural-development policy varies significantly from one Member State to another. For instance, the trade-offs between forest-related policy goals generate horizontal and vertical incoherence and fragmentation between sectoral and national interests that have important implications for forest management at the landscape level. The rather low uptake of forestry-related measures in the CAP (2007–2013) is striking. Member States only utilised 42% of the EU funds available for forestry-related measures. To illustrate, only 13% of the funding for forest-environment payments (measure 225) were used by national governments (Szedlak, 2013). This is also the case for Natura 2000 payments where only 16% of the funding was utilised. This reveals an imbalance between EU policy goals and their implementation at the Member State level through the uptake of forestry-related measures.

Table 8

Domestic implementation of EU Rural Development Policy (RDP) 2007–2013		
Country	EU RDP incoherencies	State of national forest policies
Bulgaria	◗ Nature conservation goals conflict with forest management and wood production goals.	◗ Wood production remains dominant, despite inclusion of EU climate and nature conservation goals.
France	◗ Wood mobilisation goals conflict with both biodiversity goals and traditional forestry practices.	◗ EU climate and energy targets are pursued through wood mobilisation, while maintaining Sustainable Forest Management / multifunctional and environmental goals.
Germany	◗ Cross-regional (federal government to federal states) variations in the implementation of biodiversity policy. ◗ Nature conservation goals in conflict with energy policy.	◗ Policy measures addressing EU climate change targets were already in place (e.g. forest conversion and remediation programmes). ◗ Federal states (e.g. Bavaria) adopted their own biodiversity strategies with alternative targets (horizontal incoherence).
Ireland	◗ Coherent in its afforestation goals but in conflict with recreational use of forest landscapes and renewable energy policy (e.g. wind turbines).	◗ Private afforestation increased radically due to EU RDP, while subsequent changes in nature conservation (e.g. Natura 2000) and agricultural support reversed this trend.
Italy	◗ Spatial variations (e.g. mountainous vs. plain areas) in nature conservation goals and production forestry.	◗ Attention paid to forests in plain areas has grown, while seminatural forests are increasingly abandoned. Nature conservation measures have changed from ex ante interventions to ex post restoration.
Lithuania	◗ Environmental values are integrated into wood production but there are incoherencies between afforestation, renewable energy and environmental goals.	◗ EU policy (e.g. climate) has been adapted in a top-down fashion, while the forest sector has remained relatively unchanged since independence, opposing significant forest reforms.
Netherlands	◗ Afforestation measures and the expansion of production forestry conflict with nature conservation goals and local management (e.g. reducing active management).	◗ Influence of EU policies (e.g. Natura 2000) is perceived as strong, with concrete effects on forest management.

Portugal	◗ Absence of forestry policy instruments for set rural- development targets. ◗ Lack of regulatory reinforcement and continuity.	◗ Forest policy has weakened (in terms of a command-and-control approach) in recent years. ◗ Production forestry dependent on EU incentives.
Slovakia	◗ Nature conservation goals are in conflict with forest management goals. ◗ Policy goals set for forestry practices are incoherent (e.g. conflicting measures are required by law).	◗ Major policy conflicts between forest and nature conservation actors (e.g., for Natura 2000 non-interventions zones).
Sweden	◗ Lack of cross-sectoral coordination (e.g. water and forest policy). ◗ Nature conservation goals are in conflict with forest management goals.	◗ Forest Kingdom Policy has been influenced by rural development and employment policies.

Source: Sotirov et al., 2015

In conclusion, forestry measures under the CAP and Rural Development Policy can potentially be used to regulate the climate- and biodiversity-related transition of forestry mainly through positive economic incentives involving forest environmental payments. However, due to national-level flexibility and the variety of conditions under the policy and legal framework/environment for forestry in the EU countries, as well as the complex multilevel EU funding architecture, the national uptake of rural-development-related forestry measures is subject to a range of challenges. If EU climate, biodiversity and clearcutting avoidance goals are to be met, the uptake of socioecological forestry measures by Member States needs to be increased; there also needs to be further improvement in the coherence between (on the one hand) the use of sub-measures supporting climate change resilience and biodiversity of forests, and (on the other) key sub-measures supporting forestry investments and socioeconomic aspects (EC, 2017; Geitzenauer et al., 2017).

3.4 National level

3.4.1 National forest policy regulations

The design and implementation of policies regulating forest management depend on several policy, socioeconomic and ecological drivers at the national and regional level. These include different ecological (climatic, topography, vegetation) conditions, different forest policy priorities and socioeconomic developments, *forest ownership* structures, and forest management traditions (Winkel et al., 2011). National (and sub-national) forest policy and institutional frameworks have evolved over decades, in so doing highlighting different policy and management priorities. Established in domestic forest law and reinforced in national forest strategies to meet the variety of increasing and often competing societal demands made on forests, different countries in Europe have developed different clusters of forest policy and management priorities (Table 9).

A substantial majority of all forests in the EU are even-aged and between 20 and 80 years of age (FOREST EUROPE, 2020). The even-aged structure of much of the forest resource in the EU countries indicates the widespread legacy and current practice of rotational forest management. This includes managing forests through silvicultural systems such as clearcutting, uniform or strip shelterwood, and coppice forests (Mason et al., 2022). Clearcutting remains the most common forest harvesting method in temperate and boreal forests worldwide. This is in part because it facilitates the artificially supported regeneration of light-demanding species in forests, and in part because it is economically most efficient and commercially attractive (Bliss, 2000; Franklin et al., 2000; Kimmins, 2011; McDermott et al., 2010).

Table 9

National forest policy and management priorities across Europe					
Paradigm	Sustainable timber production		Multipurpose forestry		Ecosystem management
Goal	Focus on periodic timber yields		Focus on periodic timber yields and other forest services		Focus on ecological improvement or maintenance of forest
Regional patterns					
Regions (selected countries distributed approximately)	Northern Europe, Baltic States: Finland, Sweden, Norway, Estonia, Latvia, Lithuania	Central and Eastern Europe: Austria, France, Germany, Czech Republic, Poland, Slovakia, Slovenia, Bulgaria, Romania, Croatia	Western Europe: Denmark, Ireland, United Kingdom, parts of Spain and Portugal	Southern Europe: Greece, Italy, Portugal, Spain	Western Europe: Belgium, the Netherlands, Luxembourg
Forest area (relative share)	Large	Medium	Small	Medium	Small
Economic importance of forest sector	Great	Moderate	Little	Little	Marginal
Key services of forest ecosystems for society	**Wood production** in managed semi-natural forests **Other services** (Recreation, biodiversity) mostly in protected areas	**Wood production** in managed semi-natural forests **Other services** (recreation, biodiversity) and **products** partly integrated in managed semi-natural forests, partly in protected areas	**Wood production** and **other services** (recreation, biodiversity) mainly in planted forests	**Non-wood** (game, berries, mushrooms) and **wood products** (fuel-wood), and **other services** (wildfire, soil and water protection, recreation) partly in semi-natural forests, partly in protected areas	**Biodiversity, recreation** mainly in semi-natural managed forests and protected areas **Marginal wood** production in semi-natural forests

Adapted from Sotirov et al., 2020

The dominance of even-aged forests created and managed by uniform clearcutting is also evident in the EU countries, especially in North, Central-West and Central-East Europe (EFI, 2016). Clearcutting is also found to be the second most common forestry practice in the management of mixed forests (i.e. those composed of two or three tree species) in Europe, just behind shelterwood silvicultural systems (Pach et al., 2018). Under the clearcutting regime, the main goal has been on the production of wood, with the provision of other ecosystem services having largely been a "by-product" of management (Biber et al., 2015).

In European countries, the specific national policy and legal framework governing rotational forest management, most notably clearcuts and reforestation requirements (Tables 10 and 11), echoes the forest policy and management priorities shown above. In terms of intercountry commonalities, nearly all legislations of EU countries include either regulations for obligatory reforestation after final cutting (e.g. clearcutting) or at least the normative idea of avoiding vanishing of forests after (clear)cuttings. Remarkably, despite the lack of legally binding EU forest policy, a common European policy and legal approach on obligatory reforestation after clearcutting and/or loss of forest cover can be identified. It may be formulated as follows: a cleared (e.g., clearcut or burnt) area on forest land shall be reforested over a certain timeframe (usually 2–5 years), to be specified further by national forest management authorities. The owner of the forest shall restock forest stands that are lost due to clearcuttings, forest fires, or salvage logging (by means of clearcutting) after drought-, storm- and disease-driven damage to forest stands. Restocking can be performed chiefly by artificial reforestation or afforestation (with species and quality of forest reproductive material to be specified under separate national and EU legal rules) or by natural means (natural succession). However, few thresholds or clear criteria are provided for meeting climate resilience and biodiversity friendliness goals of restocking measures (Bauer et al., 2004).

Table 10

National policy and legal framework governing clearcutting in European countries (EU and European Environment Agency): an overview by regulatory type and country group

	Type 1	Type 2	Type 3
Policy and legal approach	Clearcutting ban by law (with few exemptions)	Clearcutting allowed by law, but with clearcut size limits or with other specific restrictions	Clearcutting allowed by law, with no general clearcut limits (few specific exemptions), but with procedures
Countries	Bulgaria, Italy, Slovakia, Slovenia, Switzerland	Austria, Belgium, Czech Republic, Estonia, Germany (most Länder), Latvia, Lithuania, Poland, Romania, the Netherlands	Denmark, Finland, France, Germany (Federal Level, few Länder), Ireland, Portugal, Spain, Sweden, the UK

Source: Sotirov et al., 2022

Table 11

An overview of specific details of national legal provisions regulating clearcutting and reforestation in European countries (EU and European Environment Agency)

	Clearcutting						Reforestation			
	From area size	Notification required from	max. width	Prohibited?	Max. area allowed	Restrictions?	Obligatory?	From area size	Extension possible?	Extension possible?
Austria		0.5 ha	50 m	no	2–3 ha	yes	yes	-	5–10 years	5 years
Belgium	0.5–3 ha	-	-	no	10–25; 1–5	yes	-	-	-	-
Bulgaria	(2 ha)	-	-	yes	0	yes	yes	-	1	-
Czech Rep.	-	-	-	no	1-2 ha	yes	yes	-	2	-
Denmark	-	-	-	no	-	no	yes	-	10	-
Estonia	-	-	-	no	-	-	yes	1 ha	3	
Finland	-	-	-	no	-	no	yes	-	10–25	-
France	1–10 ha	-	-	no	-	no	yes	-	5	-
Germany	-	2 ha	-	no/yes	-	yes	yes	-	3-5	-
Ireland	-	-	-	no	-	no	yes	-	-	-
Italy	-	-	-	yes	(2 ha)	yes	-	-	-	-
Latvia	-	-	50 –100 m	no	5–10 ha	-	yes	-	3	-
Netherlands	0.5 ha	0.5 ha	-	no	-	no	yes	-	-	-
Poland	-	-	-	no	6 ha	-	yes	-	5	-
Portugal	-	-	-	no	(2 ha)	yes	-	-		
Romania	-	-	-	no	3–5 ha	yes	yes	-	2	-
Slovakia	-	-	2 aver. tree length of the parent stand	yes/no	3–5 ha	-	yes	-	2	10 years
Slovenia	-	-	-	yes	-	-	yes	-	-	-
Spain				no		no	yes		5	
Sweden	-	0.5 ha	-	no	20–50 ha	no/yes	yes	-	3	-
Switzerland	-	-	-	yes	-	-	yes	-	no	-
UK	-	-	-	no	-	no	yes	-	10	-

Source: Sotirov et al., 2022

By way of an overall conclusion, Table 12 summarises the multilevel and multisectoral policy and legal drivers of forest management in Europe. It becomes clear that some sets of EU and national policies encourage more the environmental aspects of forest management (carbon sequestration and/or biodiversity conservation) resulting in a decrease of wood use. By contrast, another set of EU and national policies encourage increased wood use by placing an economic emphasis on bioenergy and/or material wood products. Nevertheless, some EU and national policies are advocating multifunctional and/or sustainable forest management priorities.

Table 12

Multilevel and multisector policy and legal framework for forests in Europe

Increase in wood use	⟵	⟶		Decrease in wood use	
Priority level	Bioenergy and carbon (harvested wood products) forestry	Wood yield forestry	Multipurpose forestry	Carbon forest management (forest sinks)	Forest biodiversity conservation
Global	**Bioenergy and carbon (harvested wood products) forestry**	International Tropical Timber Organization (ITTO); Forest Law Enforcement, Governance and Trade (FLEGT))	UN Forum on Forests (UNFF) / International Arrangement on Forests (IAF) Forest Stewardship Council (FSC) / Programme for the Endorsement of Forest Certification (PEFC)	United Nations Framework Convention on Climate Change (UNFCCC) (Reducing Emissions from Deforestation and Forest Degradation (REDD+))	Convention on Biological Diversity (CBD)
Pan-European			Forest Europe Sustainable Forest Management criteria and indicators		
European Union	Renewable Energy Directive Bioeconomy Strategy LULUCF	Bioeconomy Strategy European Union Deforestation Regulation (EUDR) / EU Timber Regulation (EUTR) / EU Action Plan on Forest Law Enforcement, Governance and Trade (FLEGT)	Common Agricultural Policy (CAP) Rural Development Regulation (Forest Strategy)	Green Deal LULUCF Regulations Fit for 55 (Bioeconomy Strategy)	Green Deal Forest Strategy Biodiversity Strategy Nature Restoration Law Habitats/Birds Directives Deforestation Regulation
National	Forest policy and law in North, Central and East Europe	Forest policy and law in North and East Europe	Forest policy and law in Central and East Europe	Forest policy and law in West Europe	Forest policy and law in West and South Europe

Source: Produced by Sotirov, 2023

3.4.2 Patterns in national forest property rights

Safeguarding and ensuring synergies between forest ecosystem services is an increasingly important justification for state intervention in forest ownership by means of regulatory instruments. Regulatory frameworks at national and regional levels are designed to set, prioritise or encourage forest owners, managers and resource users in order to achieve desired multiple policy objectives. Property rights are fundamental institutions that define the rules governing who is allowed to use, manage and control forest resources and related forest ecosystem services (Dade et al., 2022). These rules are, in turn, formally reflected in national or regional regulatory frameworks that influence the distribution of *de jure* forest property rights and thus have an impact on economic and procedural aspects of forest management, who receives forest ecosystem services, and the extent to which these services (including wood supply) are available for society and on the market (Dade et al., 2022; Nichiforel et al., 2018).

Considering that 58% of European forests are privately owned (UNECE and FAO, 2020), private forest owner (PFO) property rights – especially withdrawal and management rights – determine the scope of these owners to individually decide on the supply of wood and delivery of forest ecosystem services, subject to the rationale and efficacy of legal implementation of forest-related policies (Bouriaud and Schmithüsen, 2005).

Nichiforel et al. (2018) have designed a 'forest property right distribution index' to provide a structured comparative overview of the impacts of multiple regulatory frameworks on the property rights of PFOs in Europe. This research documented substantial variation in PFOs' property rights, notably as regards rights i) to make decisions in operational management and the formulation of management goals: ii) to withdraw wood resources from an owner's forest; and iii) to exclude others from the use of forest resources. More precisely, in relation to the 'Distribution of withdrawal rights', the above authors found out that, in 42% of jurisdictions, the amount of wood that may be harvested can be decided by the forest owners, with restrictions imposed in exceptional cases or in a framework of general technical provisions (i.e. Austria, Belgium, Finland, France, Germany, Netherlands, Norway). At the other extreme, in 29% of jurisdictions owners cannot decide on the amount of wood to be harvested, this being set by the provisions of a mandatory management plan (i.e. Bosnia and Herzegovina, Croatia, Greece, Hungary, Poland, Slovakia, Slovenia). In the remaining 29% of jurisdictions, the amount that can be harvested (under the owner's own supervision) is provided for as a quantitative threshold in the relevant legislation (i.e. in Bulgaria, Czech Republic, Estonia, Italy, Lithuania, Romania). Moreover, in most of the countries, forest owners are required to inform authorities or obtain their approval before wood harvesting commences. Even in this respect, important differences exist; in some nations, owners need to inform authorities only in special cases when they plan to commence harvesting, and in others, approval must be sought in any situation.

Nichiforel et al. (2018) also found that many differences in relation to the 'Distribution of management rights' exist between jurisdictions with regard to regulation of forest management planning and the way wood harvesting is subsequently dealt with. Forest management plans (FMPs) are not compulsory in 38.7% of jurisdictions, but can be required for specific situations (i.e. Germany, Finland, Sweden, Norway). In 29% of the jurisdictions, an FMP is required only if the size of the property is above a certain threshold area (i.e. Bulgaria, Czech Republic, North Macedonia, France, Portugal, Switzerland, Romania, Poland). By contrast, in former socialist countries, an FMP is always required, regardless of property size and the nature of the forestry works the owner intends to carry out (i.e. Bosnia and Herzegovina, Croatia, Hungary, Slovakia, Slovenia). Large disparities also exist between countries with regard to FMP formulation. Whereas PFOs were free to choose the management goals in 19.3% of jurisdictions (i.e. Denmark, Finland, Netherlands, Norway, Spain, Sweden), the forest owners' interests were not factored into planning procedures at all in 6.5% of jurisdictions (Bosnia and Herzegovina, North Macedonia). Beyond these two contrasting situations, forest owners' participation in the definition of FMP goals varied from active involvement in setting the management goals within the limits of the law (41.9% of jurisdictions – i.e. Austria, Belgium, Germany, Estonia, France, Ireland, Latvia, Lithuania) to a formal consultation with limited possibilities of influencing the forest management goals (29% jurisdictions – i.e. Bulgaria, Croatia, Czech Republic, Greece, Hungary, Switzerland, Slovenia). The above authors also identified a broad correlation between PFOs' scope for decision-making and jurisdictions' former sociopolitical background and geographical distribution. PFOs in jurisdictions with an enduring westernised sociopolitical background (i.e. 'old' EU Member States) have a greater degree of freedom to make and implement decisions about their forest lands than do PFOs in former socialist countries (new EU Member States).

Forest property rights are an important factor regarding management goals and decisions
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In westernised sociopolitical jurisdictions ('old' EU Member States) the property rights of PFOs are significantly greater. These differences manifest in the management objectives of PFOs and their ability or willingness to supply wood. Moreover, this also has implications for the adaptive capacity of PFOs to cope with current challenges such as climate change, the increasing industry demand for wood as a raw material, and the marketing of innovative wood products.

Additionally, Nichiforel et al. (2020) compared the legal framework in place in the mid-1990s with that in place in 2015, using the "forest property right distribution index" to measure changes over time and space. Overall, most of the changes identified in the last two decades across Europe were recorded in the categories 'Distribution of management rights' and 'Distribution of exclusion rights'. These changes reflect two general trends in European forest policies: firstly, that towards expanding and reinforcing the landowners' individual rights, while preserving minimal rights for other categories of forest users; and secondly, that towards promoting the use of financial instruments when targeting policy goals related to environmental discourse.

With regard to geographical patterns, the above authors found that, in the mid-1990s, there was a clear distinction in property rights distribution between the western European countries (which give more freedom of decision-making to PFOs) and the former socialist countries entering the transition period (which had state-centred forest regulatory frameworks). PFOs in most western European countries already had considerable decision-making power in the mid-1990s, following deregulation trends in forest policy during the 1980s (Arts et al., 2010), moving from centralised 'command-and-control' approaches to market-based, self-regulatory and voluntary measures (Glück et al., 2005). And, for the next two decades, distribution of rights remained largely stable. For these countries, the substance and direction of changes indicate that the chief pressures on forest-focused legislation comes from environmental discourse (e.g. biodiversity and climate change policies). In contrast, former socialist countries in the mid-1990s granted lower decision-making powers to PFOs than in any of the Western European countries; over the next 20 years, these exhibited remarkable changes in management, exclusion and withdrawal rights. As a result of these changes, there is no longer a clear line between western and former socialist countries with respect to the national governance systems used to address *private forest ownership*. Nevertheless, with the exception of the Baltic countries – which have moved towards the western system of forest governance – most of the former socialist countries still maintain a state-centred approach in private forest management (Nichiforel et al., 2020).

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Chapter 4

Forest ownership, socioeconomic and geopolitical factor

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SUMMARY AND KEY MESSAGES

Forest ownership, demographic changes among landowners, and geopolitical developments have a profound impact on the supply of wood. While there are differences in forest ownership between European regions, the share of private forest ownership has increased since the early 1990s. At the same time, the heterogeneity among private forest owners (PFOs) has increased over time. This is reflected in a growing proportion of non-traditional, urban, passive or absentee PFOs that mirrors general demographic trends in terms of ageing and urbanisation of the population.

These changes in forest ownership pose a challenge for wood supply. Stagnating population growth in the EU, together with the projected ageing and decline in total population in many Member States and a largely urbanised society, is likely to result in lower demand for forest products and to offer a reduced labour supply. These changes affect the willingness of PFOs to undertake active forest management, and largely shape their behaviour vis-à-vis policy changes, market developments, and climate change impacts. Importantly, wood harvesting and profit maximisation are not the only – or even the primary – motivation for many forest owners and, therefore, are not the main goal of their management practices. Personal and societal factors are often more persuasive than economic rationalities. These socioeconomic developments result in reduced interest or capacity among forest owners to supply wood to the market.

Geopolitical developments such as war in Europe, as well as trade tensions between the EU and BRICS countries (Brazil, Russia, India, China and South Africa), in conjunction with the negative socioeconomic impacts of the COVID-19 pandemic, reinforced the emerging trend towards shifts from global to regional supply chains. This trend is likely to continue, due to the political will of the EU and other regions to be more self-sufficient. Regionalisation of supply chains will seriously impact the EU forest sector, in particular regarding the sourcing of wood and access to growing export markets.

In addition, if economic sanctions imposed on wood commodity imports from the Russian Federation and Belarus due to the Ukraine war continue, the gap between the demand for wood and its supply in the EU market will further increase. Finally, increasing electricity prices, reinforced by sanctions on Russian hydrocarbons and the sabotage of the Nord Stream natural-gas pipelines, will make the energy-intensive European wood-based industries less competitive. If this situation continues, the competition for wood sources will increase, and it will be strengthened by policy initiatives in the energy sector such as the REPowerEU plan.

4.1. Forest ownership patterns

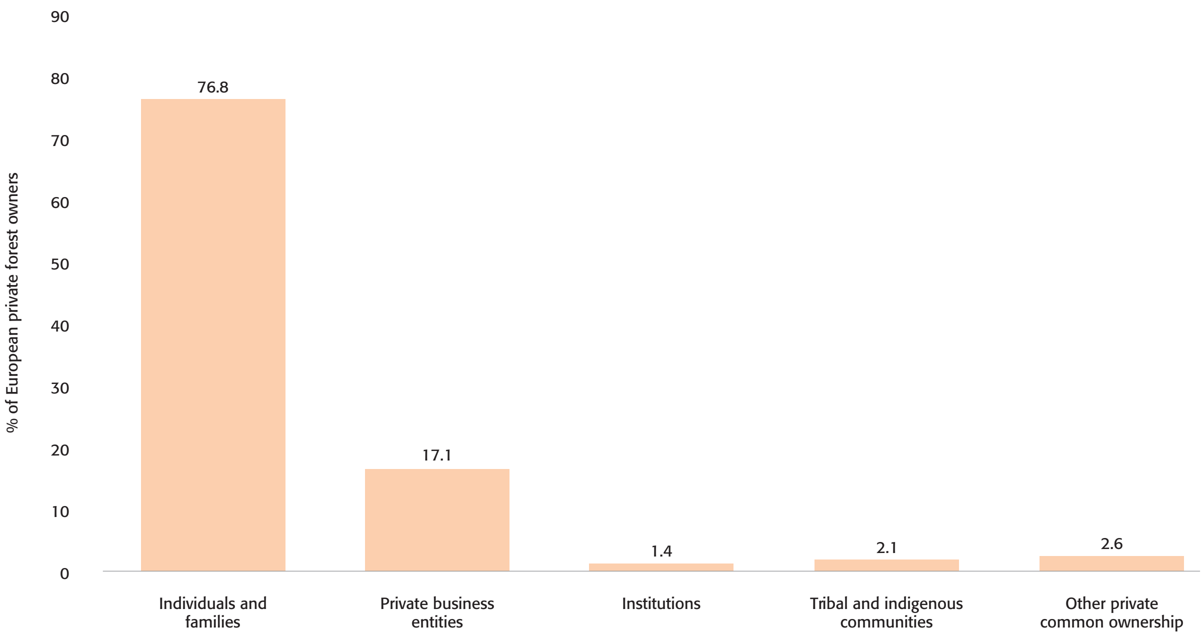
4.1.1 Forest ownership distribution

Globally, forest ownership structure varies greatly by country and region, with about 20% of the world's forest area being privately owned. The data also indicates that 56% of forest under private ownership is owned by individuals and families, referred to as private forest owners (PFOs). 29% of private forest land are owned by private business entities, with 15% managed by local communities and indigenous people. Compared with the rest of the world, Europe has a higher share of private ownership, with 56% of the forest area privately owned; of this, the majority (76.8%) is owned by individuals and families (Figure 13) (UNECE and FAO, 2020).

Because each country has a unique set of historical, legal and social circumstances, private ownership varies greatly across Europe, ranging from 0.5% in Turkey to 97% in Portugal (FOREST EUROPE, 2020) (Figure 14). With regard to the size of private forest property, very small and fragmented forest properties prevail in Europe, where 88% of forest properties are smaller than 10 ha (UNECE and FAO, 2020).

Figure 13

European private forest ownership distribution (%)



Source: UNECE and FAO, 2020

Moreover, private forest ownership clearly dominates in North, Central-West and South-West Europe, whereas the proportion of forests in public ownership is highest in Central-East and South-East Europe (Figure 14 and Table 13). Public forest properties are, on average, much larger than private ones. However, the sizes and numbers of both vary greatly between countries. Smaller properties tend to be found in South-East Europe, and larger ones in North Europe (FOREST EUROPE, 2020). Forest ownership patterns play a central role in supplying forest ecosystem services, especially provision of wood to the market. Consequently, the supply of wood varies significantly between regions and countries in Europe (UNECE and FAO, 2020).

4.1.2 Forest ownership changes in Europe

As stated in section 4.1.1., patterns of public and private ownership vary greatly across Europe, but nevertheless several common trends can be observed. In general, private ownership has increased across all European countries since the early 1990s. Over the period from 1990 to 2015, private forest ownership rose by around 22.2%, whereas public ownership declined by 2.2%. This reflects an overall increase in forest area and in privatisation of publicly owned forests (FOREST EUROPE, 2020).

In North Europe, public ownership decreased by 15.7% over the same period, mainly due to restitution and privatisation processes in the three Baltic countries (Estonia, Latvia and Lithuania), with major changes seen between 1990 and 2000. In the Scandinavian countries, changes due to privatisation were negligible. Private ownership in North Europe underwent a steady increase of 11.5% over the period 1990–2015 (FOREST EUROPE, 2020).

In Central-West Europe, both public and private ownership increased from 1990 to 2015, with a more pronounced increase in private forests. This increase was due to afforestation and reforestation programmes, as well as natural succession, in both ownership categories. A similar situation was found in South-West Europe, with an even stronger increase of more than 20.4% in the public and 28.1% in the private ownership category (FOREST EUROPE, 2020).

In Central-East and South-East Europe, a considerable shift in ownership structure occurred in the period after 1990, due to restitution and privatisation of formally nationalised forests (Weiss et al., 2019; Živojinović et al., 2015). Generally, in these regions, public ownership showed a moderate decrease, with the share of privately-owned forests growing (Dobšinská et al., 2020; Drăgoi and Toza, 2019; Pezdevšek Malovrh et al., 2017; Sarvašová et al., 2015).

Table 13

Share of public and private ownership, by region, 2015

Region	Public ownership (%)	Private ownership (%)
North Europe	29.8	70.2
Central-West Europe	37.0	63.0
Central-East Europe	85.7	14.3
South-West Europe	24.5	75.5
South-East Europe	90.5	9.5

Source: FOREST EUROPE, 2020

The outcome of the privatisation and restitution processes is a large number of new small-scale and fragmented private forest properties, whose owners often lack the knowledge, skills and capacity for efficient and sustainable forest management (Bouriaud et al., 2013). Moreover, previous research on forest ownership changes has shown that, in the last two decades, diversity of forest ownership has been constantly changing in Europe as a result of various social, economic and political drivers (UNECE and FAO, 2020; Weiss et al., 2019). However, all of these changes are taking place only gradually, and are deeply interconnected with legal and social conditions in each country (FOREST EUROPE, 2020).

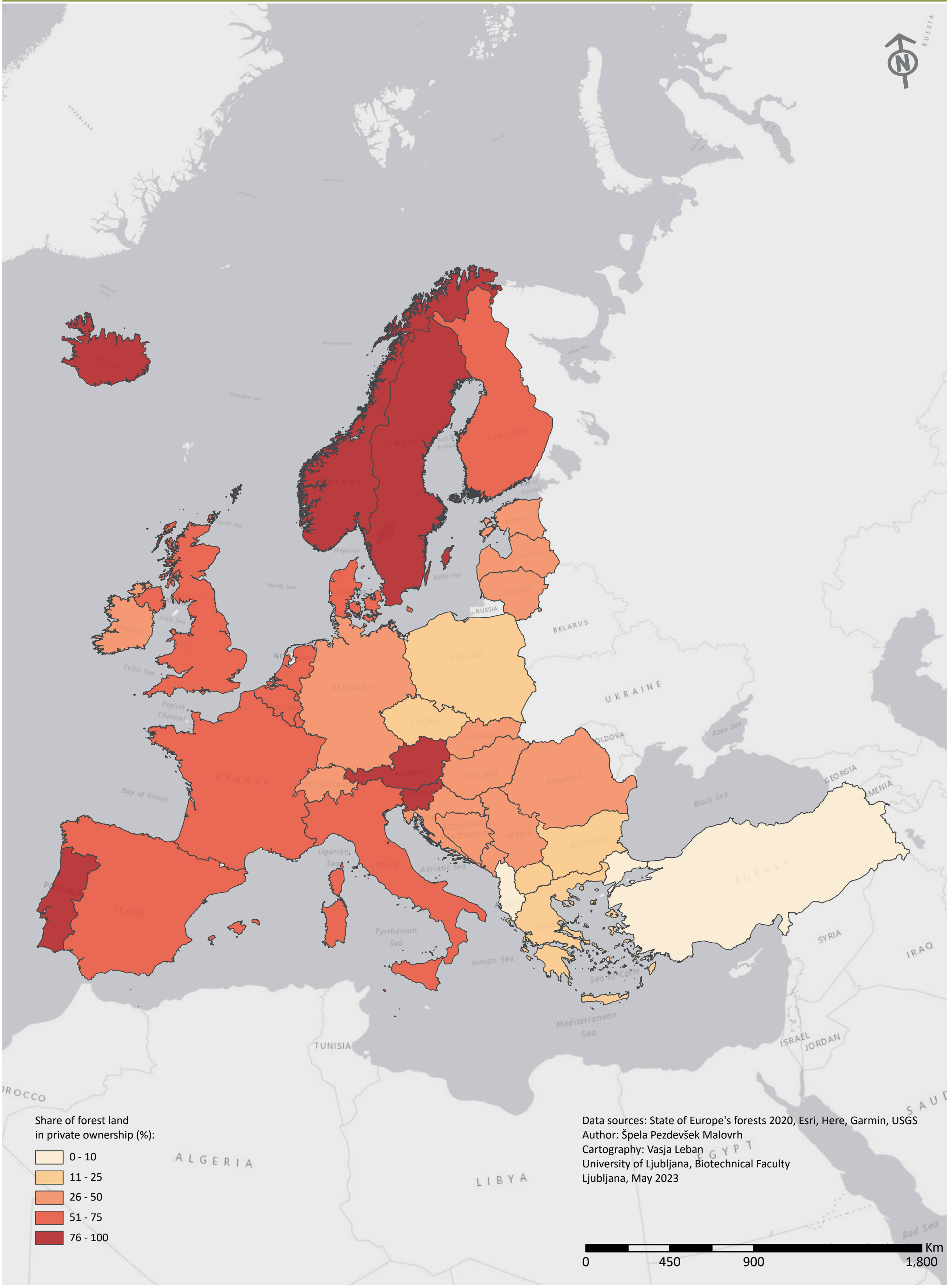
Profound socioeconomic and demographic changes – including urbanisation, ageing and associated shifts such as industrialisation of the European agricultural sector and decline in family farming systems – have become the most apparent drivers of forest ownership and forest management change in all European countries (Hogl et al., 2005; Wiersum and Ros-Tonen, 2005). These socioeconomic shifts have led to fragmentation of forest properties after inheritance, alienation due to minimal involvement of forest owners in forest management, and PFOs' increasing detachment from the land, which has been termed 'absenteeism' (Weiss et al., 2019; Ziegenspeck et al., 2004).

Previous studies have clearly shown that there is a great deal of heterogeneity among PFOs, as reflected in a growing proportion of non-traditional, urban, passive or absentee PFOs (e.g. Eriksson and Fries, 2020; Matilainen and Lähdesmäki, 2023). For example, purely economic objectives (i.e. those pursued in production-oriented or 'traditional forestry', as it is referred to) are no longer prevalent, with more and more PFOs interested in multiobjective forest management (Živojinović et al., 2015). This has led to a growing diversity of private owners' interests, their values and demands placed on their forests, and the way they manage them, which in turn influence hierarchies of priorities in their management decisions (Weiss et al., 2019). These changes are deemed a risk from the perspective of providing forest ecosystem services, particularly the supply of wood to the market, as well as regarding the ability to address risks facing forests, such as biodiversity loss and climate change adaptation (Blanco et al., 2015; UNECE and FAO, 2020).

The increasing heterogeneity of PFOs in Europe represents a significant challenge for forest policy-makers as well, in view of continuing uncertainty as to how intensively private forests are and will be managed in the future (e.g. Ficko et al., 2019; Lawrence and Dandy, 2014). The growing industrial demand for wood has meant that the increase in sustainable mobilisation of forest resources (mainly wood production) – and especially from 'unmanaged or under-utilised' private forests – has been placed high on the EU and national forest policy agenda (Hirsch and Schmithüsen, 2010). As a result, a wide range of different policy instruments have been implemented to promote increased wood harvesting. Examples include wood mobilisation programmes, incentives for reducing the cost of harvesting wood, support to enhance PFO cooperation, and advisory programmes tailored to specific owner groups aimed at enticing PFOs to be more proactive in wood harvesting (Lawrence, 2018; Petucco et al., 2015).

Figure 14

Share of forest land in private ownership in Europe



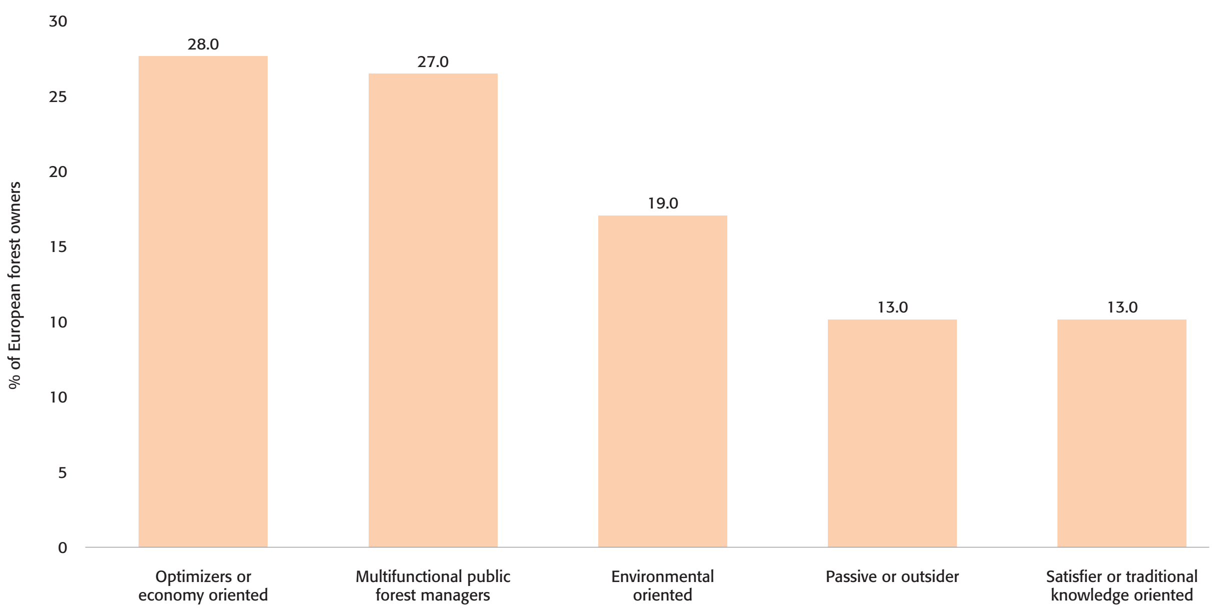
Source: FOREST EUROPE, 2020

4.1.3 Forest owners' profiles and their behaviour models

Several scientific studies explain and predict PFOs' forest management behaviour using different theoretically driven models or typologies (e.g. Kilham et al., 2019; Trubins et al., 2019). Research confirms that a range of different PFO profiles exist in Europe, including their management objectives, socioeconomic characteristics and management strategies. PFOs generally fall into 2–6 profiles, with a variety of names/labels to describe the diversity of their behaviour vis-à-vis forests and forest management (124 names found). Most often PFOs are described as 'multi-objective' or 'multifunctional', but labels/categories such as 'passive', 'uninterested' and 'recreationists' are also used to describe PFOs who do not fit the traditional definition of PFOs undertaking regular economic-oriented forest management. In addition, PFOs are often labelled as 'investors and farmers', 'indifferent', 'conservationists' and 'self-employed owners' (Ficko et al., 2019).

Figure 15

Distribution of private and public forest owners' types in Europe (%)



Source: Deuffic et al., 2018

Moreover, a comparative study (Deuffic et al., 2018) found five types of private and public forest owners in 10 European countries (Bulgaria, France, Germany, Ireland, Italy, Lithuania, Netherlands, Poland, Slovakia and Sweden), despite the variety of political, socioeconomic and ecological contexts involved (Figure 15).

The most prevalent PFO types are the 'optimisers or economy-oriented PFOs' and the 'multifunctional public forest managers'. Moreover, these findings also confirm the importance of economic objectives (e.g. wood production and supply of wood products) as drivers of forest management. However, a substantial proportion of PFOs are forest owners who seek to balance wood production and other related forest ecosystem services in multiple-objective management planning contexts and approaches. All of these forest owners' meta-profiles have been found in the various regions of Europe, although some regional differentiation exists, especially between West and Central-East European countries, since in the latter PFOs' behaviours are still under rather strict control by the forest state administration (see Chapter 3.4.2) (Deuffic et al., 2018).

Sotirov et al. (2019) further developed the above-mentioned forest owners' meta-profiles with associated behaviour models and related distinct forest management approaches, including objective and management strategies. These six refined meta-profiles and behavioural models describing forest owners include: 'optimisers' (FO-1), 'traditionalists' (FO-2), 'maximisers' (FO-3), 'passives' (FO-4), 'multifunctionalists' (FO-5) and 'environmentalists' (FO-6) (Table 14).

Table 14

Overview of forest owners' meta-profiles and their behaviour in Europe

Forest owner type	General description	Ownership group and property characteristics	Forest management approaches
FO-1: 'Optimisers'	◗ Mainly interested in making profits and income from forest commodities sold on the market ◗ See environmental (amenity) values as limitations to economic profitability ◗ Markets are preferred as the main policy and governance mechanism ◗ Reject state control and are sceptical about regulatory policy instruments, but still adhere to basic rules that secure property rights and economic sustainability ◗ Remain sceptical about social control and moral suasion by civil-society groups and the public	◗ Private and industrial forest owners; commercially oriented public forest companies ◗ Large-scale properties	Intensive, profit-oriented, even-aged forestry while respecting (minimal) rules
FO-2: 'Traditionalists'	◗ Main objective is wood production ◗ Seek to satisfy (and not maximise or optimise) their household needs while respecting inter-generational family rules ◗ Forest seen as a savings bank, standing capital to be used sporadically when needed. ◗ Place greatest importance on social norms, traditional knowledge and routines, and less so on legal norms	◗ Private forest owners including forest cooperatives ◗ Small to medium-scale properties	Low-intensity, close-to-nature forestry

FO-3: 'Maximisers'	◗ Share similar behavioural rationality as FO-1 ◗ Do not respect rules that regulate property rights and/or economic sustainability ◗ Are not in favour of any rules constraining short-term gains from intensive forestry ◗ Do not adhere to moral suasion and try to escape social control ◗ Can trap in a common pool dilemma and/or consider doing activities against the rule of law and/or regulated forest management	◗ Private and industrial forest owners; commercially oriented public forest companies ◗ Large-scale properties	Highly intensive (short-rotation) profit-oriented forestry; sometimes without respecting rules (e.g. 'illegal loggers')
FO-4: 'Passives'	◗ Have no or little interest in economic profits and active forest management ◗ Tend to regard self-initiative in forest management as burdensome. ◗ Have socially reactive and passive behaviour regarding price signals and markets ◗ Retain a reserved attitude with a low degree of openness to regulatory changes and moral sanctions. This group largely consists of small-scale non-industrial private forest owners who are highly educated and have urban values and an urban lifestyle	◗ Private forest owners (mostly non-industrial private forest owners who are highly educated and have urban values and an urban lifestyle)	Passive/little management due to lack of interest in forestry

FO-5: 'Multifunctionalists'	◗ Show high responsiveness to state regulations, formal/legal rules, and professional norms ◗ While they have an economic interest in wood use, they generally feel obligated to observe regulations governing multipurpose forestry ◗ Economic aspects are not key to public forest managers, and they can sometimes be critical of profit-oriented forestry	◗ State and municipal properties ◗ Large-scale properties	Medium-intensity, mixed-objective forestry
FO-6: 'Environmentalists'	◗ Believe in amenity values of forest biodiversity conservation and 'close-to-nature' forest management ◗ Act out of inner conviction and a sense of duty to implement these environmental beliefs as the 'right' thing to do ◗ Accept 'reasonable' state regulations only when they support their environmental values and ecosystem management ◗ Remain critical of conventional wood production-oriented forestry and suspicious of (self-) regulation by markets ◗ Support non-state, market-driven forest governance (e.g. forest certification) when they can act in line with their amenity-related beliefs and values	◗ Public and private owners; environmental groups as forest owners ◗ Small to medium-scale properties	Passive non-intervention and/or extensive forest management or restoration-oriented forest management

Source: Sotirov et al., 2019

4.1.4 Factors influencing forest owners' management and harvesting decisions

Despite the growing industrial need to increase wood supply, and irrespective of the supportive EU and national policy frameworks, the increase in sustainable wood mobilisation has been hampered in many regions in Europe due to forest ownership structure, differing profiles on the part of forest owners, and the impact of social, political and economic factors. As a result, substantial quantities of technically available wood have remained unused (Verkerk et al., 2011). Therefore, from the perspective of the wood industry, and also of policies that promote and support sustainable wood production, it is important to know which factors influence forest owners' decision-making on forest management and wood harvesting.

Previous studies have shown that different groups of factors influence forest owners' decisions on forest management and wood harvesting (e.g. Poje et al., 2016; Silver et al., 2015). For example, Beach et al. (2005) conducted a comprehensive review of econometric studies on private forest management, in which factors that determine owners' forest management behaviour were classified into four categories: market drivers, policy drivers, PFO characteristics, and plot/resource conditions. They found that, in the 'market drivers' category, a wood price variable was most frequently included in the models, followed by the interest rate. These authors also found relatively few studies that included the 'policy drivers' category. By contrast, they ascertained that many studies include PFOs' socioeconomic or demographic characteristics, such as income, education level, age and owner proximity. In the 'plot and resource conditions' category, property size and growing stock are the most common variables included in the models. Additionally, Sotirov et al. (2019) divided factors that influence forest owners' behaviour into two groups: agent-based factors and structural factors. Agent-based factors include forest owners' behaviour and decision-making rationalities, and are connected to structural/external factors, including political (e.g. policy and legal changes), economic (e.g. markets, prices), environmental (e.g. climate change, biogeographical conditions), societal (e.g. public opinion, societal pressure) and technological (e.g. product and process innovations) developments.

The previously mentioned studies show how the five meta-profiles of forest owners in Europe (for details see section 4.1.3.) would have reacted, and are likely to react in the future, to external/structural policy and economic, environmental and technological developments (Table 15). These findings provide useful guidance about whether and how the forest management decisions of different forest owner types can be influenced through external regulatory, economic, technological and societal incentives and disincentives.

Table 15

Responsiveness of forest owners to key external factors

Forest owner type	Behavioural reaction to external factors (weak -- to strong ++)				
	Policy	Market	Environment	Knowledge, Innovation	Societal norms
FO-1: 'Optimisers'	+	++	-/+	+/-	-/+
FO-2: 'Traditionalists'	+/-	+/-	-	++	++
FO-3: 'Passives'	-	-	+	-	-
FO-4: 'Multifunctionalists'	++	+	+/-	++	++
FO-5: 'Environmentalists'	+	-	++	++	+

Source: Deuffic et al., 2018

Previous studies exploring PFOs' decisions on wood harvesting have also shown a relationship between these owners and a large variety of factors (e.g. Heinonen et al., 2020; Lawrence, 2018; Poje et al., 2016). The following were highlighted as the most influential factor in each category: wood price in the market category; awareness of policy, key forest policy instruments and membership of organisations in the policy category; age, gender, education, income, and management objectives and management priorities in the PFO socioeconomic or demographic-characteristics category; and forest property size and distance from residence to property in the plot/resource category. However, researchers reported that magnitude and statistical significance on wood harvesting intentions and intensities are not consistent across studies (Blanco et al., 2015; Ficko et al., 2019; Silver et al., 2015) (Table 16).

Table 16

Factors associated with private forest owners' wood harvesting behaviour – summary

Category of factor	Factor	Relationship between factor and harvesting behaviour	Reference examples
Market category	Wood price	More likely to harvest when wood price increases	Bashir et al., 2020; Petucco et al., 2015
		Ambiguous response to wood price	Dennis, 1989; Kuuluvainen et al., 1996
Policy category	Awareness of policy and key forest policy instruments	Owners aware of policy and policy instruments are more likely to harvest	Bashir et al., 2020; Sjølie et al., 2019
	Membership in organisations (forest owners' organisations)	Members of organisations are more likely to harvest	Bashir et al., 2020; Petucco et al., 2015; Sjølie et al., 2019
Private forest owners characteristics category	Age	Older owners are less likely to harvest	Bashir et al., 2020; Petucco et al., 2015; Poje et al., 2016
	Gender	Female forest owners harvest less than male owners	Bashir et al., 2020; Eriksson, 2018; Follo et al., 2017
	Education level	Educated owners are more likely to harvest	Bashir et al., 2020; Staal Wästerlund and Kronholm, 2014
		Educated owners are less likely to harvest	Häyrinen et al., 2015
	Income	Owners with higher income are less likely to harvest	Kuuluvainen et al., 2014; Nordlund and Westin, 2011
		Owners with higher income are more likely to harvest	Juutinen et al., 2020; Petucco et al., 2015

	Forest management objectives and priorities	Production-oriented owners are more likely to harvest	Favada et al., 2009; Petucco et al., 2015
		Amenity-, conservation- and recreation-oriented owners are less likely to harvest	Bashir et al., 2020; Häyrinen et al., 2015
		Absentee owners are less likely to harvest	Baardsen et al., 2009; Lien et al., 2007
Plot/resource condition category	Forest property size	Owners of larger properties are more likely to harvest	Eggers et al., 2014; Petucco et al., 2015
	Distance from residence	Owners living far away from their forest property are less likely to harvest	Bashir et al., 2020; Silver et al., 2015

Source: Blanco et al., 2015; Ficko et al., 2019; Silver et al., 2015

Based on the review of factors influencing PFOs' forest management and wood harvesting behaviour, it can be concluded that a growing number of studies show that 'maximisation of profits' is not the only, or even the chief, motivator for forest owners' wood harvesting behaviour. Still, large-scale economically oriented PFOs and multifunctional public managers are likely to remain the main suppliers of wood on the market as they respond well to market and/or policy signals (Deuffic et al., 2018). By contrast, small-scale PFOs – as well as many PFOs in general – are found to be less responsive to market drivers (wood price) (Lawrence, 2018). Personal and social factors are often more persuasive than economic ones. The following are more likely to harvest wood: younger male private owners with larger forest properties; those living closer to their forest properties; production-oriented owners; those who need income from their forests; owners who are aware of policy and policy instruments; and members of forest owners' organisations. Therefore, it is important that forest policy decision-makers and extension service providers recognise that factors other than wood price are more important in prompting PFOs to supply wood, and that alternative information pathways, communication campaigns and services aimed at these owners should be explored (e.g. Juutinen et al., 2020; Wilkes-Allemann et al., 2021).

4.2 Socioeconomic and geopolitical factors

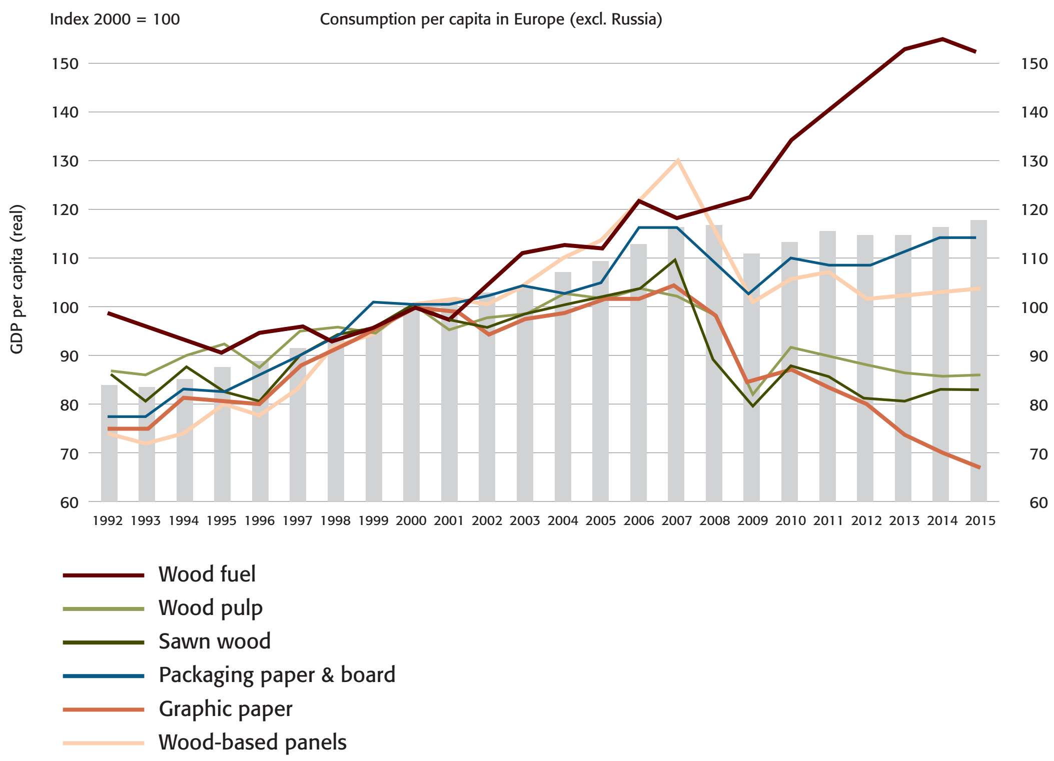
Overall economic development and demographic features are interlinked factors frequently cited as driving change in demand for, and provision of, forest products (e.g. FAO and UNEP, 2020; UNECE and FAO, 2022). Furthermore, geopolitical developments – even if we discount their most extreme manifestation, i.e. international wars – have the capacity to profoundly change the relevant framework and conditions for society as a whole, the forest-based sector included (Agrell, 2019). There follows an overview of these factors and how they could affect European forest product markets, notably wood supply, in the future. Although there are obviously some differences between countries, overarching trends are evident and common. Hence, the review will mostly be at an aggregated level.

4.2.1 Economic development

Economic growth is associated with growing demand for products and services, including those that are wood-based. However, there are signs that the demand for traditional, bulk wood products in Europe has become decoupled from gross domestic product (GDP) growth (Figure 16). According to neoclassical growth theory, economic growth is driven by growth in population (i.e. labour supply), by capital, and by technological change, and the continued growth of the economy is contingent upon the creation of new technology (Solow, 1956; Swan, 1956), driven by enhancement of a nation's human capital (Rivera-Batiz and Romer, 1991). Furthermore, with increasing incomes, countries move up the hierarchy towards a pattern of demand that focuses more on less basic needs (Ernst, 1978).

Figure 16

Consumption per capita of wood-based products and gross domestic product (GDP) growth in Europe (excluding Russia)



Source: Jonsson et al., 2017

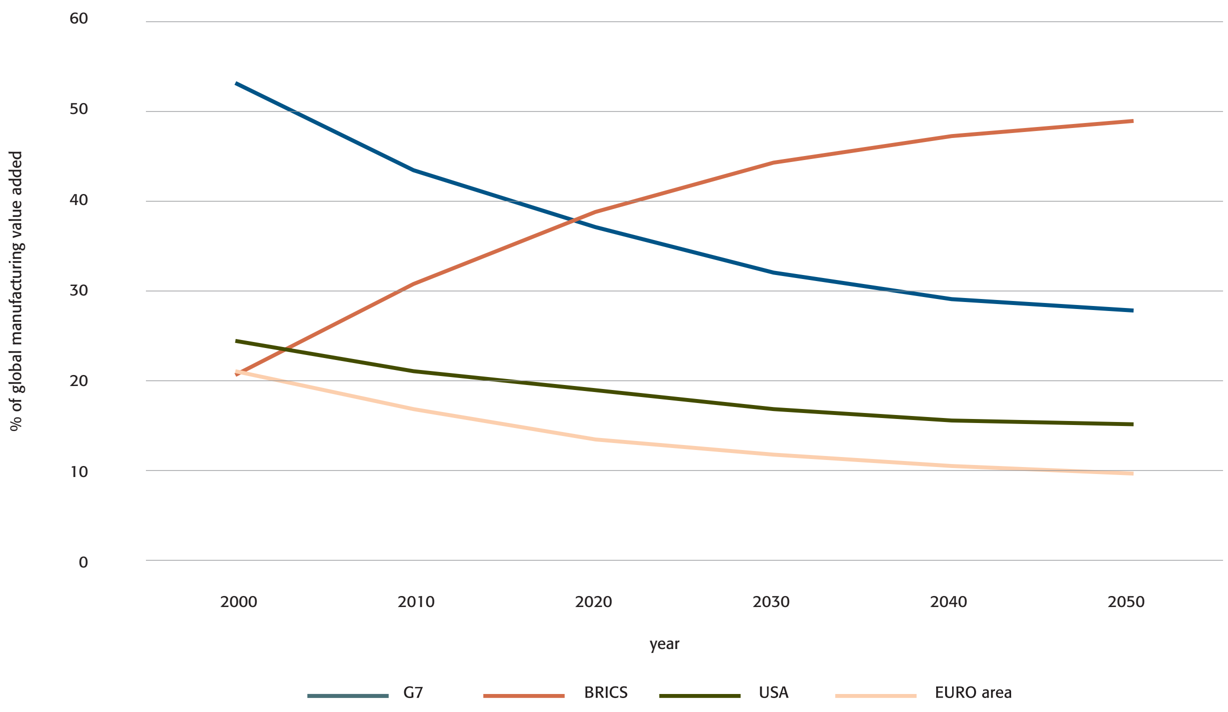
Developed economies (G7 countries – Canada, France, Germany, Italy, Japan, United Kingdom and United States) accounted for most of global GDP until 2000. However, more rapid growth in developing economies is tipping the balance in the latter's favour (Figure 17), even though economic growth is foreseen to slow down in these countries as well (Table 17). Hence, the global demand for forest products is expected to continue to grow, but mainly in Brazil, China, India and other developing or transitioning countries. Major investments in science and technology – as in the EU, where Member States collectively have research and development expenditures above 2% of GDP (Eurostat, 2023a) – could favour the transition to a knowledge-based bioeconomy (see Chapter 5).

The current rate of economic growth in Europe is much lower than in developing countries, partly as a consequence of stagnating population growth, and it is predicted to slow further in the future (Table 17).

The most notable trends in the recent past have been those in global manufacturing, with China having overtaken both the US and the EU during the last decade. China now accounts for a share of global manufacturing value added (MVA) equalling that of the US and EU combined (Figure 18).

Figure 17

Share of global gross domestic product (GDP)



Source: OECD, 2022

Table 17

Average annual real gross domestic product (GDP) growth

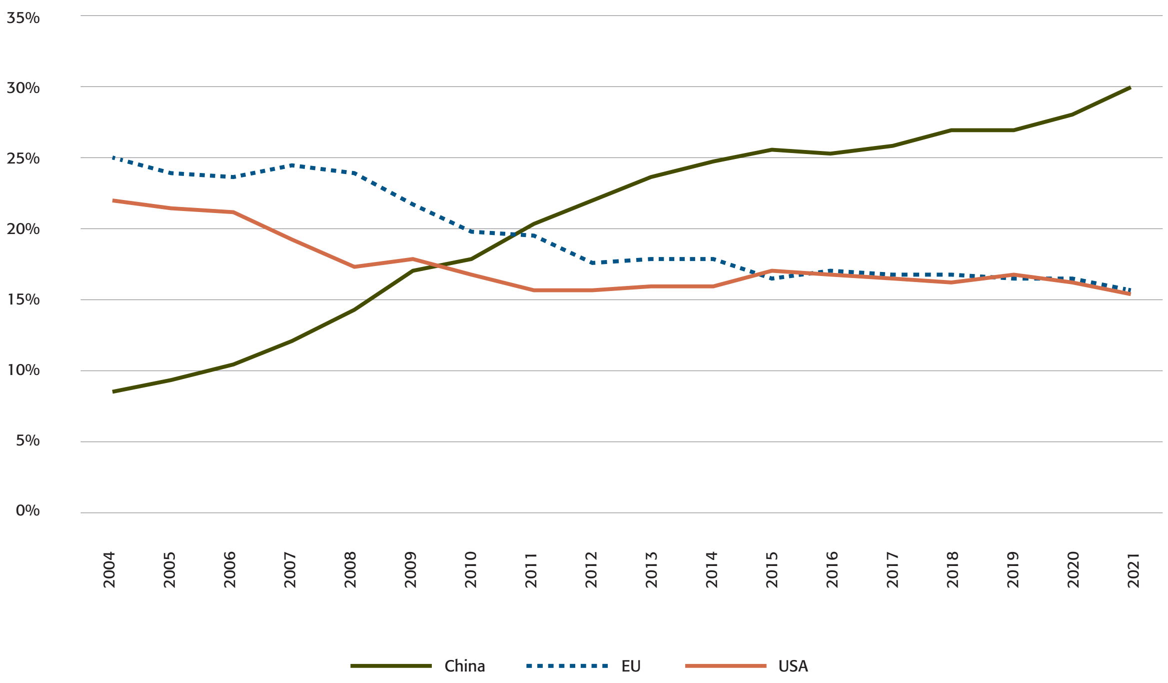
	2021–2030	2031–2040	2041–2050	2051–2060	2021–2050
Austria	1.7%	1.1%	1.0%	1.1%	1.3%
Finland	1.5%	1.1%	0.9%	0.8%	1.2%
Germany	1.5%	0.7%	0.9%	0.9%	1.0%
Latvia	2.2%	0.4%	-0.1%	-0.4%	0.8%
Poland	2.6%	1.1%	0.3%	0.2%	1.3%
Euro area	1.9%	1.0%	1.0%	1.2%	1.3%
US	2.3%	1.4%	1.4%	1.3%	1.7%
China	4.6%	2.5%	1.5%	1.3%	2.9%
India	7.0%	4.2%	2.9%	2.4%	4.7%
World	3.4%	2.1%	1.6%	1.5%	2.4%

Source: OECD, 2022

In the immediate and shorter term, economic development at global and EU level is very much affected by events related to the crises triggered by the Ukraine war. Sanctions and other disruptions to trade have exacerbated inflation – mainly through exorbitant energy and food prices – and adversely affected economic growth (Arriola et al., 2023; OECD, 2022). This also highlights the distinction between overarching trend patterns and shorter-term developments, the latter being hard to foresee. Possible geopolitical ramifications and ensuing implications for the forest products sector are discussed in section 4.2.3 below.

Figure 18

Share of global manufacturing value added



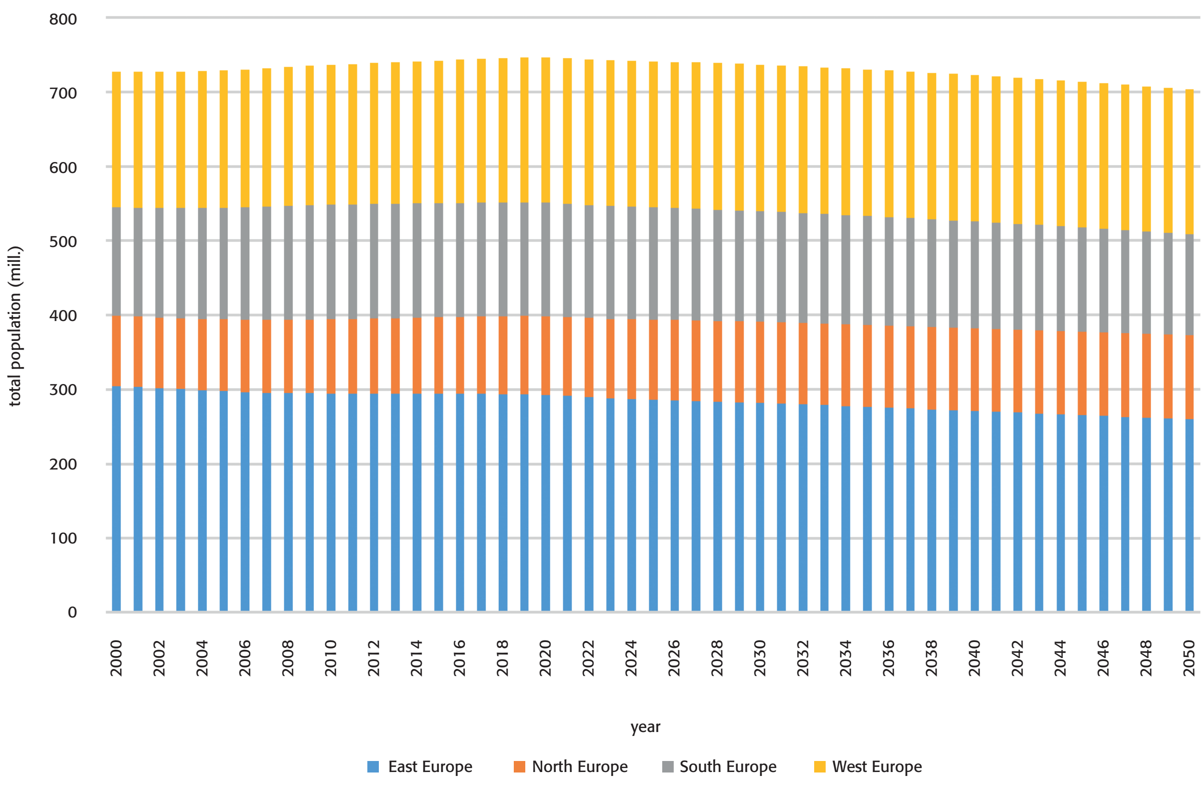
Source: World Bank, 2023

4.2.2 Demographic developments

Demographics affect forest product markets in several ways. First of all (as already mentioned), population increase can result in economic growth and increased demand, and vice versa. A sizeable population also provides a large domestic market. Rapid population growth, however, also imposes constraints on the development of savings and thus, subsequently, on investments, as it leads to a larger number of dependent children (Cook, 2005; Meier and Rauch, 2005). The world's total population is projected to reach 9.7 billion by 2050, and stabilise at around 10.4 billion by 2086, according to UN medium fertility forecasts (UN, 2023). Sub-Saharan Africa will account for more than half of the world's population growth between 2022 and 2050. Europe's total population peaked at 746 million in 2020, and is projected to decrease to 703 million by 2050 (Figure 19). The EU population, according to recently updated projections (March 2023) that account for increased immigration (notably from Ukraine following the Russian invasion, but also from Africa and the Middle East in the wake of regional wars and other events), is projected to increase from 446.7 million in 2022 and peak at 453.3 million in 2026, before gradually decreasing to 447.9 million in 2050 and to 419.5 million in 2100, according to the baseline projection (Eurostat, 2023b). This projected fall in population – most pronounced in Southern and Eastern EU – is one crucial factor behind the expected slow economic growth in Europe. However, for twelve EU Member States and three European Free Trade Association (EFTA) countries, the projected population size will be higher in 2100 than in 2022, this change being entirely prompted by positive net migration (see Table 18). The decreasing labour force poses challenges for the provision of forest products (e.g. wood), affecting forest management as well as wood processing. This will, among other things, necessitate further automation in the forest-based sector. In terms of housing demand, the number of households is shown to be more important than overall population size (Jonsson, 2011). The number of households in Europe is projected to increase until 2030, as households are becoming smaller, implying that demand for housing, furniture and (hence) sawn wood and wood-based panels will continue to grow (EEA, 2005), albeit at a modest pace.

Figure 19

Average annual real gross domestic product (GDP) growth



Source: UN, 2023

Changes in age structure of the population also have potentially important effects on general economic development and markets for forest products. Global population is ageing: the share of the population above the age of 65 is projected to increase, while that below the age of 25 is projected to decrease between 2021 and the end of the century (UN, 2023). In Europe, this trend towards ageing is very pronounced, with the old-age dependency ratio projected to increase significantly (Figure 20). Rising old-age dependency is likely to negatively affect economic growth, even when adaptive strategies such as automation and increased immigration after taken into account (NIC, 2021). In particular, the proportion of the population older than 75 years is shown to have a significant negative effect on residential-construction volumes, due to the increasing burden on the working population (Lindh and Malmberg, 2008). An ageing population (in the sense of entailing a shrinking workforce) will, as pointed out earlier, also accelerate the need for technological development and automation, both in logging and in further processing. In the construction industry, more construction components will need to be factory-made (Schuler and Adair, 2003), implying increased uptake of engineered wood products (Manninen, 2014), as further detailed in Chapter 5.

Table 18

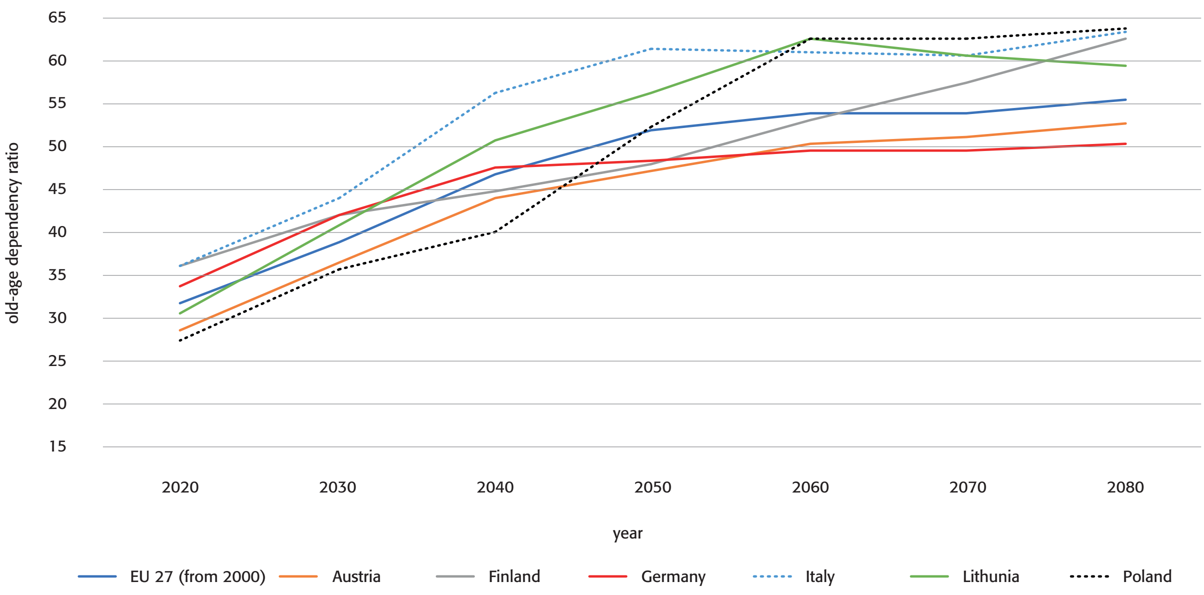
EU and European Free Trade Association populations

	Population	Cumulative births	Cumulative deaths	Cumulative natural population change	Cumulative net migration	Total population change	Projected population
	1 January 2022			2022–2099			1 January 2100
EU	446,735.3	291,262.3	416,595.9	-125,333.7	98,060.0	-27,273.6	419,461.7
Belgium	11,617.6	8,975.7	10,540.0	-1,564.2	2,502.6	938.4	12,556.1
Bulgaria	6,838.9	3,693.1	6,633.6	-2,940.6	1,173.6	-1,767.0	5,072.1
Czechia	10,516.7	7,808.9	9,885.6	-2,076.7	2,205.7	129.0	10,645.7
Denmark	5,873.4	4,538.3	5,376.5	-838.2	1,090.8	252.6	6,126.1
Germany	83,237.1	58,027.4	78,538.7	-20,511.4	21,391.6	880.2	84,117.3
Estonia	1,331.8	925.2	1,294.8	-369.6	327.1	-42.5	1,289.5
Ireland	5,060.0	4,361.8	4,666.6	-304.8	1,116.2	811.4	5,871.4
Greece	10,459.8	5,017.2	9,246.4	-4,229.1	1,052.0	-3,177.1	7,282.5
Spain	47,432.9	27,417.7	46,032.3	-18,614.6	16,303.2	-2,311.4	45,121.4
France	67,871.9	52,842.6	60,065.6	-7,223.0	7,393.9	170.9	68,042.8
Croatia	3,862.3	1,949.4	3,606.7	-1,657.4	617.7	-1,039.7	2,822.7
Italy	59,030.1	29,905.1	57,526.3	-27,621.2	18,785.6	-8,835.6	50,194.5
Cyprus	904.7	695.6	774.7	-79.1	182.2	103.1	1,007.7
Latvia	1,875.8	903.1	1,654.6	-751.4	41.6	-709.8	1,165.8
Lithuania	2,806.0	1,279.1	2,664.6	-1,385.5	355.2	-1,030.3	1,775.7
Luxembourg	645.4	627.1	675.1	-48.0	399.8	351.8	997.3
Hungary	9,689.0	6,600.5	9,212.5	-2,612.0	1,977.1	-634.9	9,054.1
Malta	521.0	422.4	618.3	-195.9	434.0	238.1	759.1
Netherlands	17,590.7	13,277.2	16,226.6	-2,949.4	3,669.1	719.7	18,310.4
Austria	8,978.9	6,289.3	8,485.6	-2,196.2	2,794.0	597.8	9,576.6
Poland	37,654.2	21,008.5	34,373.8	-13,365.4	5,227.1	-8,138.2	29,516.0
Portugal	10,352.0	5,753.5	9,818.2	-4,064.7	2,693.8	-1,371.0	8,981.1
Romania	19,042.5	11,428.2	16,999.9	-5,571.7	1,138.8	-4,432.9	14,609.5
Slovenia	2,107.2	1,335.1	1,977.0	-641.9	485.5	-156.4	1,950.8
Slovakia	5,434.7	3,397.2	4,922.5	-1,525.3	643.0	-882.2	4,552.4
Finland	5,548.2	3,268.8	5,137.9	-1,869.1	1,105.6	-763.5	4,784.9
Sweden	10,452.3	9,514.2	9,641.4	-127.2	2,953.1	2,825.9	13,278.2
Iceland	376.2	422.6	389.5	33.1	215.4	248.6	624.5
Norway	5,425.3	4,328.7	5,059.0	-730.3	2,036.6	1,306.2	6,731.6
Switzerland	8,738.8	6,609.4	8,097.5	-1,488.1	2,853.6	1,365.5	10,104.3

Demographic balances, 1 January 2022–2100
Source: Eurostat, 2023b

Figure 20

Old-age dependency ratio (ratio between population aged 65 years or over divided by population aged 15 to 64 years, expressed as a percentage)



Source: Eurostat, 2023b

Urbanisation – as well as being a factor in trends regarding total population size, the number of households and the age structure of the population – also influences markets for forest products. Increased urbanisation tends to increase society's demand for non-wood forest products and services relative to wood products (UNECE and FAO, 2005), with an increasing focus on non-material ecosystem services such as recreation (Masiero et al., 2019), while also potentially reducing roundwood harvests as forest management is affected far beyond urban boundaries (Vickery et al., 2009). In addition, urbanisation, along with ageing and decreasing dependence on forestry income – key aspects in the structural change of PFOs taking place in numerous European countries (see section 4.1.) – poses further challenges to the supply of industrial roundwood (Häyrinen et al., 2015), as discussed in detail in section 4.1.4. Furthermore, by reducing the rural workforce, increased urbanisation exacerbates the difficulty of attracting people to work in forestry (Andersson, 2018), putting upward pressure on labour costs and thus stimulating mechanisation. Global urbanisation is expected to increase further until 2050 (UN, 2018). In the EU, populations are projected to grow in almost three out of five urban regions, while they are expected to shrink in four out of five rural regions by 2050 (Eurostat, 2021).

4.2.3 Geopolitical developments

As for the geopolitical crises prompted by the recent and ongoing Russian invasion of Ukraine, the Council of the EU largely banned the import of wood from Russia and Belarus covered by the EU Timber Regulation from entering the EU in 2022 (CEU, 2022). This trade policy choice in response to this 'wild card' – a highly unlikely, but high-impact event – geopolitical development has had direct negative impacts on wood supply on the EU-27 market, at least in the short term. For example, Russia, Belarus, and Ukraine supplied almost 10% (8.5 million m3) of Europe's total consumption of softwood in 2021, while Russia alone accounted for over 43% (or 5 million m3) of EU roundwood imports in the same year (source: United Nations Commodity Trade Statistics Database – UN Comtrade, 2023). Nordic countries have been the major EU importers of roundwood from Russia; Finland accounted for 92% and Sweden for 5.4% of EU imports of roundwood from Russia in 2021. Hence, these EU trade sanctions on non-tropical wood imports from Russia and Belarus further reduce the possibility of bridging the growing wood supply gap in Europe. This resource supply shortfall is likely to be further exacerbated by a reduced future supply of round softwood after increased events involving bark beetle infestation-induced salvage loggings across Europe, driven by advancing global climate change (see Chapter 2). Even a hypothetical lifting of sanctions is unlikely to return the Russian supply of wood products to Europe. Thus, as an example, Russia has reoriented its wood exports from Europe to China (e.g. GWMI, 2022). These import-related supply gaps also increase EU dependence on tropical-wood imports, incentivise (risky) tropical exports to the EU, and mean further risks of policy and market leakage due to shifts in harvesting to regions with lower standards (Jonsson et al., 2015). Furthermore, tropical wood is increasingly diverted to regions with less stringent legislation, notably China (Jonsson et al., 2015) as well as Balkan countries (Radosavljević et al., 2021). In the near future, placement of risky tropical wood products on the EU market is likely to be decreasing after the EU has adopted – and starts implementing – the EU Deforestation-Free Regulation with higher sustainability and legality standards, perceived as trade barriers to tropical wood (Berning and Sotirov, 2023). These import gaps, which currently do not appear reversible, thus increase reliance on – and put additional pressure on – the supply of wood from domestic forests inside the EU27.

The geopolitical crisis also has other implications for the European wood-based sector. Globalisation has led to increased trading in, and the creation of a truly global market for, forest products (Jonsson, 2011). Wood-based industry functions have become spatially separated – companies utilise materials from various sources, siting manufacturing plants at different locations along the value chain, weakening traditional ties between forest product processing and forest endowment (Bael and Sedjo, 2006). However, the COVID-19 pandemic led to disruptions in trade and supply chains, and strengthened political impetus for increased self-sufficiency within the EU (e.g. EEAS, 2022) and other regions. It appears global supply chains are gradually giving way to regional chains (Oerstroem Moeller, 2018), with supply chains in North America, Europe and Asia increasingly sourcing closer to home (Legge and Lukaszuk, 2021). Consequently, the current geopolitical crisis seemingly reinforces the already emerging trend of moving away from a truly globalised World towards a regionalised one, dominated by two competing centres of influence, namely China and the US (NIC, 2021).

Geopolitical developments have implications for import dynamics and regionalisation trends
Photo © Cristalov from iStock

Should this development continue, which seems inevitable, it will have serious consequences for a highly export-oriented EU wood-based sector, not only as regards the sourcing of wood as a raw materials, but also for exports of wood products. Hence, as an example, 35% (or 40 million m3) of the EU sawn wood production of some 113 million m3 was exported outside the EU in 2021, with the four largest Asian importers – China, Japan, Saudi Arabia, and South Korea – accounting for 23% (UN Comtrade, 2023). As regards dissolving pulp (a commodity considered to have a positive future market potential due to the substitution of man-made cellulosic fibres for cotton (Kallio, 2021), as pointed out in Chapter 5), Asian countries, in particular China, totally dominate as the recipients of EU exports, which accounted for over 54% of EU production in 2021 (Table 19). Consequently, should these growth markets become less accessible. wood-based industries in the EU will be negatively impacted to a considerably degree.

Table 19

EU exports of dissolving pulp in 2021

	Rank	Tonnes	Share
China	1	713,979	73.6%
India	2	101,671	10.5%
Indonesia	3	97,362	10.0%
Other	4	57,351	5.9%
World		**970,363**	**100%**

Source: UN Comtrade, 2023

Furthermore, elevated electricity prices within the EU – stemming from a rebound in economic activity after the COVID-19 pandemic, as well as increasing reliance on intermittent, weather-dependent energy sources (Kuik et al., 2022) – have been reinforced by sanctions on Russian hydrocarbons and the sabotage of the Nord Stream natural-gas pipelines. This situation is leading to a serious loss of competitiveness in energy-intensive industries relative to corresponding industries in regions with lower energy prices (Birol, 2023; Chen et al., 2023), not least China and the US (Ganges Post, 2023). It might also entail further relocation of manufacturing abroad (Alipour, 2023) or even industry shutdowns (Sorge, 2023). The re-opening of China from its COVID-19 restrictions will probably lead to an increase in global demand for liquefied natural gas (LNG), exacerbating the energy crisis in Europe (Birol, 2023). European wood-based industries will be impacted to varying degrees, primarily depending on the degree of national reliance on natural gas for power generation. In general, pure paper mills, mechanical pulp producers and reconstituted wood-based panel manufacturers are likely to be among the most adversely affected. These industries will suffer not only from out-of-control energy prices, but also from increased competition for wood-based raw materials from energy uses – not least under the REPowerEU Plan (EC, 2022). The latter could lead to increased demand for wood-based energy, with the relevant manufacturing processes not resulting in any sizeable amounts of residues that can be used for energy production, in particular for process energy (Jonsson, 2011). Indeed, in the case of Sweden, there have already been — so far temporary — paper mill closures due to rampant energy prices (Eriksson, 2022).

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5

Chapter 5

Technological and market factors

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SUMMARY AND KEY MESSAGES

The global demand for both short-lived and long-lived wood-based products is continuously growing. Future wood flows are highly dependent on global markets' demands, and technological developments in the European wood-based sector are a key driving force in the transition towards a circular bioeconomy.

Innovations include added-value fibre technologies and new wood-based materials and chemicals, such as construction materials, textiles, biofuels, packaging materials, bio-based plastics and platform chemicals. These emerging wood-based products are less dependent on particular tree species than traditional products are, and many types of wood can be used to produce them. European forest industries are currently investing heavily in new technologies, innovations and added-value products, resulting in a wood-based sector that integrates substantial added value by creating new value chains related to the sustainable use of wood and its products.

The sufficient availability, sustainable mobilisation and efficient logistics of high-quality woody biomass will be crucial factors for the wood-based sector in the decades to come. Sustainable mobilisation of wood biomass is affected by the demand and changing markets for wood-based products at a global scale. Strong competition between traditional and new wood-based value chains, with their increasing demand for raw-material supply, is a likely future scenario. This may require more efficient infrastructure and logistical approaches, efficient and innovative products, processes and manufacturing technologies, as well as full and circular exploitation of wood stocks.

Increase in value of wood-based products goes hand in hand with national bioeconomy strategies. Research, new knowledge and professional expertise are expected to play a crucial part in identifying the potential role of the forest-based bioeconomy in sustainable growth and societal well-being. For example, in order to improve the sustainable mobilisation of forest biomass, the complexity of the wider framework and conditions affecting it need to be properly understood, and this requires a multi-actor approach factoring in the latest technological, market and political developments.

The future of research and innovation actions should be focused on the holistic and resource-efficient use of wood materials, including side-streams and waste streams. In novel products, innovations, processes, and wood-based services, circularity and cascading aspects should be considered. And, in addition to technological developments, new circular operational business models and cocreation practices can provide new pathways for more sustainable forest industries.

5.1 Sourcing and mobilisation of forest biomass in Europe

Forests and the European forest-based sector can play a central role in the transition to a green economy and in sustainable growth. Sustainably managed forest resources are crucial as they constitute the backbone of Europe's forest-based sector. In total, there are 78 forest types in Europe with 16 coniferous and 95 broadleaved tree species – softwoods and hardwoods respectively – of relevance for wood-based industries.

In 2019, the combined turnover of the EU (EU-27) industrial sectors referred to as the bioeconomy sector totalled about 814 billion euros. The pulp and paper products sector, and wood-based industries producing wood products and furniture, account for the largest proportions of turnover, adding up to around 402 billion euros. Biofuels and bioenergy comprise about 15% of total turnover, amounting to 122 billion euros (Porc et al., 2022). The forest-based sector is important for the European economy. It accounts for around 7% of the EU´s manufacturing gross domestic product (GDP) and employs over 3.5 million people, while also boosting local business development and growth of small and medium-sized companies (CEPI, 2020; FTP, 2013).

Natural resources are expected to play a central role in the socioeconomic transition towards a green economy. Global megatrends such as climate change (Chapter 2), population growth and decline, the deteriorating geopolitical situation (Chapter 4) and the depletion of natural resources may lead to severe conflicts and to protective natural-resource policies (Chapter 3) that are very likely to emphasise regional self-sufficiency in Europe (Chapter 4). The societal shift we are undergoing on a global and epochal scale also demands radical change in energy- and resource-efficient technology, knowledge and entrepreneurship, a task which falls upon the forest-based sector (Kärkkäinen et al., 2022). Therefore, the Strategic Vision for the Year 2040 of the European Forest-Based Sector Technology Platform (FTP) aims to increase the *added value*, circularity, and diversification of production technologies by producing new low-emission fibre products and forest-based platform chemicals.

The flow chart (Figure 21) presents woody biomass flows within the European wood-based sector, showing the relationship between biomass sources and use in 2017. Use of wood within the forest sector saw gradual growth during 2009–2017. Figures for domestic removal of wood in 2017 were up by 19% compared to 2009. The overall increase in woody-biomass flows – including net-imported wood, domestic removal, and unreported primary sources – was 24% in 2017. The biggest growth in wood flow is for energy use, which amounted to more than 25% of growth (Cazzaniga et al., 2022).

As outlined in Chapter 2, the net annual wood harvest (not including salvage logging after calamity or damage) in Europe's forests corresponds to roughly 60% of the net annual increment. This represents potential for sustainably increasing the mobilisation of wood biomass for a variety of uses. However, the wider contextual frameworks at regional level throughout Europe are complex and diverse. Local conditions are defined by many factors such as forest ecosystem types, ownership structures, infrastructure, available harvesting technologies, transportation, logistics and transforming industries. Augmenting sustainable mobilisation consequently requires a multiactor and multifactorial approach. Additional innovations can originate from various innovative decision-support tools and incentives, which are most effective when adapted to local circumstances. However, recent years have seen an increase in forest calamities across Europe, which have had a huge impact in terms of increased harvested volume and oversupply of wood on the market due to unplanned salvage logging (EIP-AGRI Focus Group, 2018).

Changing demand and shifting markets for wood-based products, including emerging new markets on a global scale. have also impacted the sustainable mobilisation of forest biomass in Europe. Growing competition between traditional and new wood-based value chains, with their increasing demand for raw-material supply, may occur across Europe. This requires more efficient infrastructure and logistics plans (transportation value chains) in all regions, since long-distance transport is not an economically viable option due, for example, to limited access to seaways and rail infrastructure. Furthermore, the prices for roundwood and forest products depend on this factor (EIP-AGRI Focus Group, 2018).

5.2 New technological developments

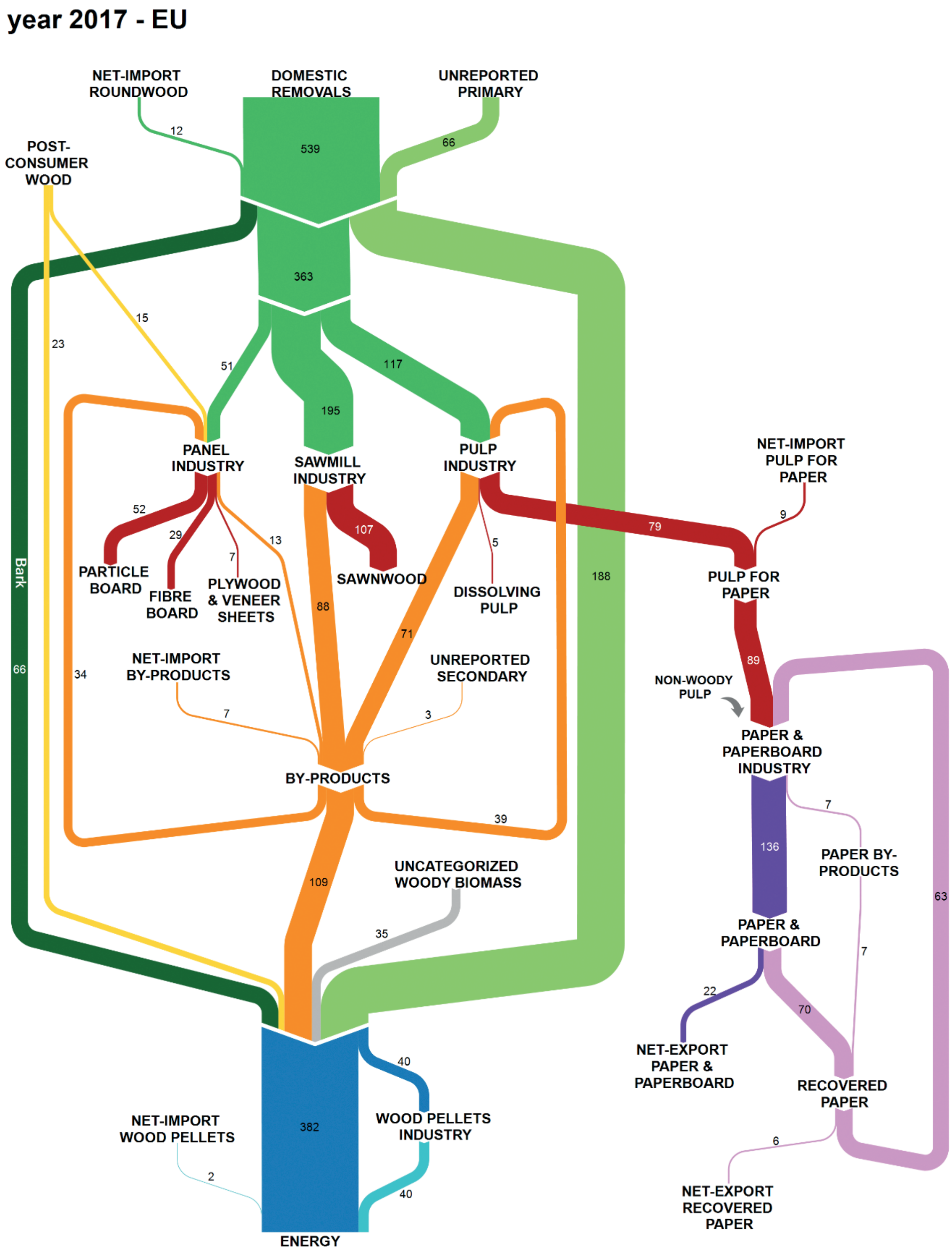
5.2.1 Digitisation

Digitisation, new remote sensing and artificial intelligence – as well as the effective and innovative uptake and utilisation thereof – are crucial in responding to changing conditions and forming new sustainable value chains and networks needed for a circular bioeconomy. For example, with the aid of new technologies, the origin of the wood used in products can be traced. Remote sensing and geospatial technologies, artificial intelligence, and modern harvesting machines can enable precise, environmentally friendly and efficient forestry operations. Digital technologies can be used to transform value chain logistics flexibly and efficiently, and permeate through the whole production system. New scanning technologies in industrial plants and sawmills allow more efficient raw-material use (FTP, 2019; Kärkkäinen et al., 2022). Several ideas have been developed that are aimed at designing a European toolbox for increasing sustainable mobilisation of forest biomass, with digitisation – as an instrument along the entire value chain – becoming an indispensable asset.

The digitisation process, along with new developments in information and communication technologies, is multifaceted and has an impact on the efficiency and performance of forestry-wood chains (Kurttila et al., 2021). These advances optimise the planning and management of forest biomass, and precisely forecast its potential availability. The entire process of planning, management, harvesting and wood supply for various uses can be carried out in an integrative manner. Previously collected electronic data in forest inventories can be used with forest models, allowing optimisation of the management and planning of forest operations, and providing quantitative and qualitative information for optimised allocation to downstream biomass transformation processes. Digitised production of semi-finished and final products enables the needs of customers, clients, and

Figure 21

Sankey diagrams of wood biomass flows in the EU; all numbers are given in million cubic metres of solid-wood equivalent (mm³ SWE), representing the amount of solid wood fibre contained in the product



Unit: million cubid meters SWE

Note: values smaller than 0.5 and trade of solid wood products are not shown.

Source: *Cazzaniga et al., 2022*

consumers to be proactively considered. In design, the reuse and performance of products can also be defined and realised with the use of data-based processes promoting and integrating a circular economy approach. This could lead to a positive impact on resource and energy efficiency along the entire production chain from primary production to the end-of-life stage of a product (Kurttila et al., 2021).

5.2.2 Wood harvesting and processing technologies

Wood harvesting and transport technologies are further key factors in economic operations. However, there is no single solution to the challenges of making them more efficient and economically viable on the one hand, yet environmentally sensitive and climate resilient on the other. This is due to the wide variation in forest ecosystems and soil structures, as well as differences in the structure of forest industries and the effect this has on demand for forest biomass across Europe.

A prerequisite for potential sustainable increase in harvested wood volumes is growing mechanisation of wood harvesting. Nevertheless, different soils, sites and other conditions will result in a range of different best-adapted solutions. This requires the further development of silvicultural and forest management strategies, as well as novel machinery.

These improvements address not only efficiency issues with traditional technology and machinery, but also the essential modification of existing business models in general, as well as adaptations in the contracting of harvesting and transport operations. Digitisation of the roundwood trade, and of information sharing between traders, will facilitate enhanced performance in forest industry operations and forest harvesting planning. New processing technologies for softwood and (especially) for hardwood species are needed in the near future. As shown before, advancing climate change (Chapter 2) and achieving ambitious environmental-policy targets (Chapter 3) will, over time, very probably lead to a shift towards more mixed forests and a strong increase in broadleaved species in Europe. The transformation of wood-based industries is a key challenge, given that current wood processing technologies (more softwoods, medium-sized diameters, even-supply flows) are insufficiently adapted to the expected changes in wood feedstocks (e.g. more hardwoods, larger- or smaller-sized wood, disrupted or non-even supply flows) (EIP-AGRI Focus Group, 2018).

5.2.3 Tools for the future of biorefineries

The bio-based chemicals market is expected to expand at an annual growth rate of 10.3% (CARG) due to the need for bio-based replacement of chemicals in a small number of fossil-based products (Nielsen et al., 2022). Growing market potential has increased interest in the development of bio-based chemicals. Recent technological advancements in industrial biotechnology, metabolic engineering and synthetic biology are prominent tools, and this extends to modern wood-based biorefineries. This includes rapid production of synthetic genes and whole genomes, data analysis and integration, improved quantitative description of metabolism using advanced metabolic models, and robotics and automation for high-throughput strain construction and characterisation (Hanczyc, 2020; Nielsen et al., 2022).

Since the biorefinery sector aims to produce a very wide array of high added-value products, it targets potential across the full spectrum of wood-based raw materials and by-products. Wood-based biorefineries are generally integrated with pulp mills, where value streams are generated either before the wood is pulped or after the pulping process. In the former case, the major focus is on the extraction of hemicelluloses originating from forest residues and/or wood chips, and on conversion to sugars that can be exploited in the production of building blocks for chemicals. And, in the latter case, added value can be created by valorising the black liquor into chemicals instead of combustion to produce heat and electricity (Söderholm and Lundmark, 2009).

5.2.4 Somatic embryogenesis of forest trees

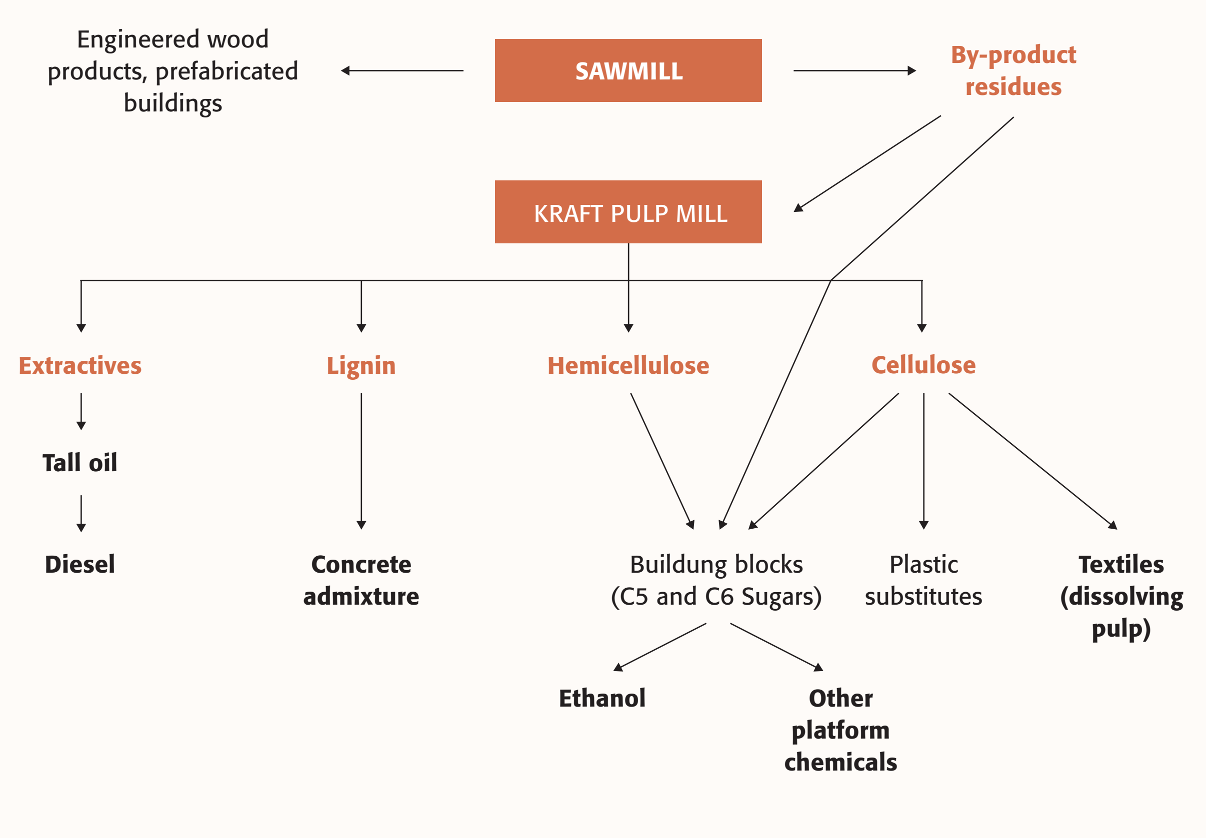
Somatic embryogenesis is the primary enabling technology for most tree biotechnological products. It offers new opportunities for tree breeding and vegetative deployment, as well as genetic-resource conservation and restoration. Since its first successful use in conifers (Chalupa, 1985; Hakman et al., 1985; Nagmani and Bonga, 1985), this new technology has been achieved for many tree species. In recent years, important advances have also been made in angiosperm species (Merkle and Nairn, 2005). Somatic embryogenesis also provides indispensable tools for research and development (R&D) in biotechnology, genomics and molecular biology. However, an important current application – in conjunction with cryopreservation – is the integration of this new technology into tree breeding and deployment programmes, in which plants derived from somatic embryogenesis are routinely produced. Furthermore, in various parts of the world, this technology is commercially implemented in high-value multivarietal forestry, especially for some spruce and pines tree species. Despite the important advantages it offers, somatic embryogenesis is often difficult to obtain (or is obtained at only a very low frequency) for certain commercially and ecologically important tree species. This requires further research and development (IUFRO, 2023).

5.3 Emerging wood-based products and their market trends

The 2040 vision for the European forest-based sector aims to increase the added value, circularity and diversification of production technologies by producing new low-emission fibre products and forest-based platform chemicals (FTP, 2020, 2019). Market trends show an increase in demand for roundwood (smaller-diameter wood and wood residues) to produce sawn wood products, panel and board, pulp, and packaging materials. The creation of new demand for forest industries' residues, and related impacts on their trade flows, can also create markets and stimulate new business developments. This requires new improved efficiency of operations in the roundwood markets. Solutions could include web-based trading, advanced wood procurement and best-adapted harvesting technologies based on efficient silviculture management models for producing roundwood and wood fibres, while safeguarding sustainability, biodiversity and adaptation strategies that take the various local conditions into account (EIP-AGRI Focus Group, 2018).

Figure 22

Overview of emerging wood product categories



Source: Hurmekoski et al., 2020

Diversified industrial use of woody biomass, and the change in the market structure in forest sector and industries, indicate that use of wood is currently growing globally. The market for printing and writing paper is declining, whereas demand for pulp, tissue paper and packaging materials has increased significantly. Emerging innovative wood products that can serve as substitutes for their emission-intensive counterparts. The use of such innovative products as construction materials, textiles, chemicals, bio-based plastics, biofuels, food additives and pharmaceuticals is increasing in the industry portfolio (Table 22). With this trend, the traditional boundaries within forest, chemical and energy industries are becoming increasingly blurred as these different industries are using the same primary wood-based feedstock and entering the same market (Hetemäki and Hurmekoski, 2020; Hurmekoski et al., 2020).

Recently, the European forest industries have started investing in new fibre technologies, sustainable paper and board processes and design, and in a range of emerging added-value, wood-based materials and chemicals. Annual investment here amounts to some 5 billion euros. However, to achieve the full potential of innovation, additional investments and new business models are required (FTP, 2019). The overview of the product categories and estimated market trends are presented in Figure 20 and in Tables 20 and 21.

Table 20

Estimated market trends of the forest product categories

Product	Growth trend	Turnover + employment implications	Market situation
Paper	decreasing	big	Mature products
Packaging materials	stable growth	big	Mature and new products
Sawn wood + veneer	slow growth	big	Mature and new products
Engineering products (e.g. cross-laminated timber (CLT))	rapid growth	small	New products
Bioenergy	growth	significant	Established products
Biofuels	growth	small	New products
Biochemicals	growth	small	Established and new products
Textiles	rapid growth	small	Established and new products

Source: Hurmekoski et al., 2020

Table 21

Summary of the key characteristics of emerging wood-product categories

	Textiles	Construction	Fuels	Chemicals	Plastics and packaging
Market size 2023 (2015)	130 Mt (90 Mt)	28000 Mt (21,500 Mt); 3.16 billion m2 (2.24 billion m2)	2300 Mt (2100 Mt)	600 Mt (330 Mt)	130 Mt (72 Mt)
Technologies	New solvents for dissolving pulp, new fibre spinning technologies	Engineered wood products, industrially prefabricated construction elements, new technologies for load-bearing frames	Diesel based on tall oil, bioethanol	Biorefinery technologies for ethylene and succinic acid for drop-in substitutes; lactic acid, furfural	Technologies for wood-plastic composites, pulp-based films, new wood fibre technologies
Target substitution	Cotton	Concrete, steel, established wooden load-bearing frames	Fossil fuels, first-generation biofuels	Petrochemicals, first-generation biochemicals (starch-based)	Fossil food, health care, cosmetic packages, and carrier bags WPC: tropical wood, car interiors
Main barriers	Technical issues	Risk perception and building codes; fragmented industry structure	Feedstock availability, conversion efficiency issues, investment and running costs	REACH and regulation, extensive validation processes, investment costs, path dependency of petrochemical industries	Uncertain legislative environment
Position in the wood-based value chain	Raw-material supplier, textile fibre producer, yarn producer	Admixture supplier, product or element supplier, main contractor	End-product producercosts	Primary and secondary platform chemical producer	Converter of packages and WPCs

Source: Hurmekoski et al., 2020

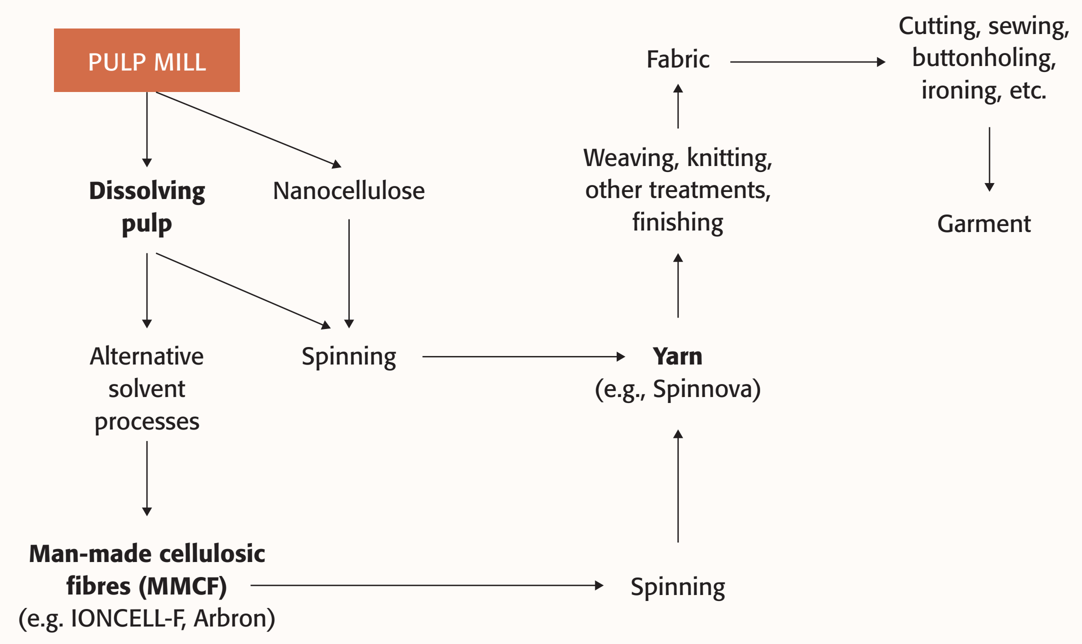
5.3.1 Wood-based textile fibres

The textile industry is one of the world's largest industrial sectors in terms of volume, with rapidly growing global demand driven by increases in population and average income (Antikainen et al., 2017). Global production of textile fibres is estimated to reach 146 Mt in 2030 (Hassegawa et al., 2021). The textile fibre market is dominated by synthetic fibres (mainly polyester) with a 69% market share, followed by cotton (23%) and man-made cellulosic fibres (7%) (Hurmekoski et al., 2018). According to recent studies, modern wood-based fibres have a lower environmental impact than cotton (which is a highly water-intensive crop), viscose and synthetic fibres (Hassegawa et al., 2022). Wood cellulose-based textile fibres provide an alternative to synthetic fibres, and their share is predicted to reach 8–10% in the future (Nousiainen, 2022).

Wood-based textile fibres can be produced from various feedstock sources including many types of wood. Currently, the most common tree genera for wood-based textiles are eucalyptus, beech, spruce and pine. Feedstock used for this covers sawlogs, pulp logs, wood chips and wood pulp. In general, wood-based textile fibres are also fully or partly recyclable. Production of wood-based textile fibres is compatible with existing value chains, being integrated (as it is) to mills in which a fibre production plant operates adjacent to a pulp mill (Hassegawa et al., 2022). Kraft pulp is a source of man-made cellulosic fibres such as viscose. The toxic and energy-intensive production of viscose has accelerated the development of new and non-harmful fibre production methods, including combined mechanical and chemical treatment – such as use of tempo oxidation and ionic liquids – to produce Spinnova, IonCell, Lyocell, and Kuura fibres (Hassegawa et al., 2022; Mestä Group, 2021; Spinnova Group, 2023). Figure 23 provides an overview of the textile value chain.

Figure 23

Textile value chain



Source: Hurmekoski et al., 2018

5.3.2 Wood-based plastics

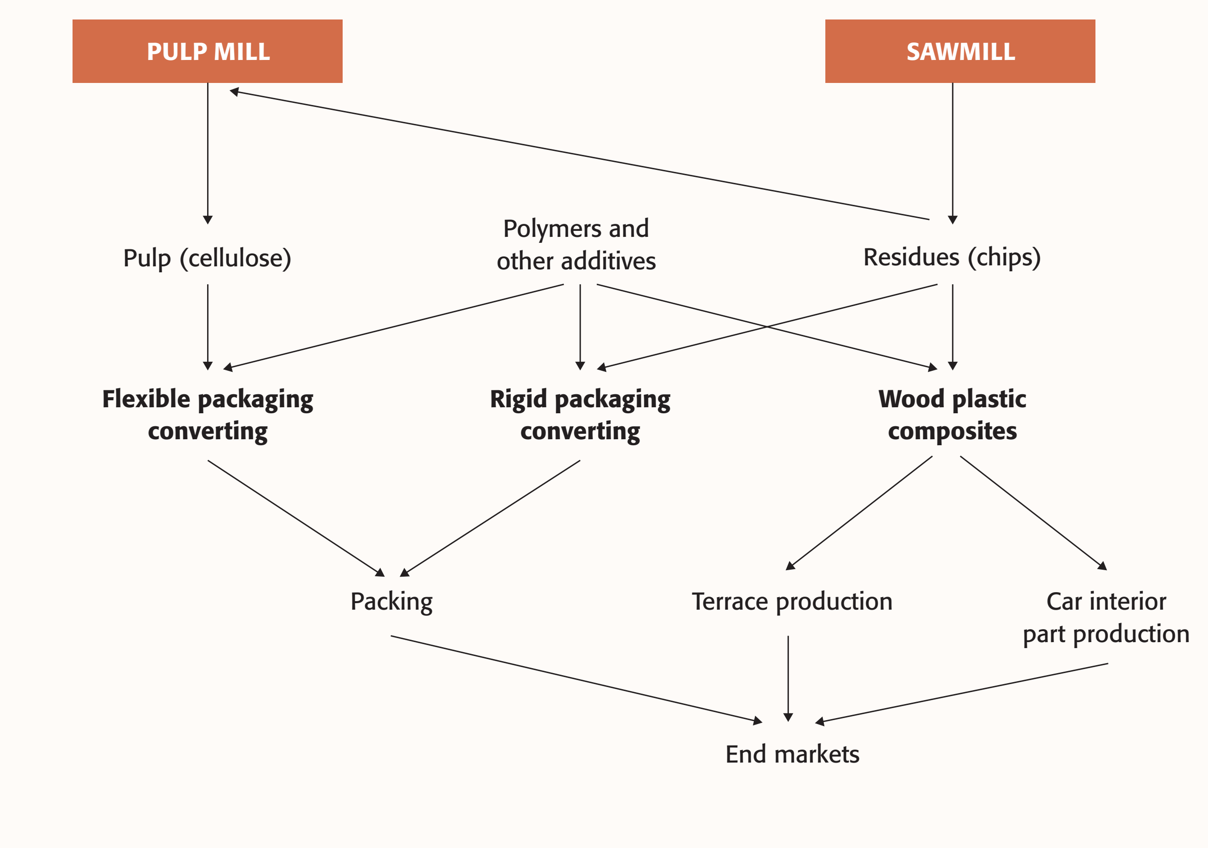
The growing market for packaging is driven by global population and GDP growth, increasing e-commerce and demand for takeaway products, as well as by regulation governing short-lived plastic products (Hurmekoski et al., 2018). The total global plastic market in 2021 was 390.7 Mt, of which the proportion of bio-based plastics was only 1.5% (5.9 Mt). Around 44% of plastics ends up in packaging. The expected market share of bio-based plastics used for packaging is estimated to be 40% by 2027 (Plastics Europe, 2022).

Current categories of wood-based plastic products include wood-plastic composites, paper-resembling films for flexible packaging and other plastic-resembling wood or composite materials for rigid packaging (Kruus and Hakala, 2017; Nägele et al., 2002). The major advantage the forest industries have in producing indirect substitute products that replace plastic is in the effective packaging value chain that enables the granulate processing step to be omitted. However, plastics are not considered to be a key business opportunity for wood-based industries, due to the technical and economic issues raised for the biochemical market (Hurmekoski et al., 2018).

The forest industry has been focusing on the development and production of bio-based plastics from second-generation feedstock, using industrial side-streams from the pulp and paper industry in particular, such as tall oil from kraft pulping. One of the advantages of using industrial side-streams from the forest industry as feedstock for bioplastics instead of annual crops, is that woody biomass originates from non-arable lands (Hassegawa et al., 2021). Cellulose is a widely used feedstock in the new packaging products that can replace plastic. These products look and feel like plastic, and can even be processed in the same way as plastics (Mäntyranta, 2019). Regenerated or recrystallised cellulose can be further processed into plastic-like films which are transparent, flexible and suitable for food packaging (Harlin, 2022). Wood-based cellulose is also shown to be suitable for thermoplastic packaging applications, such as films and coatings. Thermoplasticity can be achieved via chemical and/or enzymatical functionalisation of cellulose derivatives, such as nanofibrillated hardwood cellulose. The structure of nanofibrillated cellulose allows good barrier properties against oxygen, carbon dioxide, grease and mineral oil. These attributes make this material suitable for packaging applications where aroma restoration and long shelf-life are a high priority. The innovativeness of thermoplastic cellulose also lies in the ability to use existing feedstock and equipment in all process steps (Vartiainen et al., 2016; Willberg-Keyriläinen et al., 2017). Bio-based plastics from wood-based sources are suitable for both injection moulding and for blown-film and cast-film extrusion lines, which makes their production compatible with current production lines. Lignin, a second-generation feedstock derived from kraft pulping, has also been a building block for bio-based, single-use plastics for agricultural use, including mulch films and containers for seedlings (Hassegawa et al., 2021). The plastic and packaging value chain is presented in Figure 24.

Figure 24

The plastic and packaging value chain



Source: Hurmekoski et al., 2018

One commercialised example of wood-based plastics is UPM Raflatac Forest Film™, which is a 100% wood-based solution derived from wood-based naphtha from residue of pulp production (UPM, 2019). Another company, Woodly Oy, has developed a material based on softwood cellulose that has the same qualities as fossil plastic and can be used in recyclable packaging for food and flowers (Woodly Oy, 2023).

5.3.3 Wood composites

Wood fibre-reinforced composites are products made with wood of various feedstock sizes (wood flour, chips, sawdust, particles, fibres or solid wood) and a binding agent or thermoset. Wood composites have been used for many decades as construction material (in decking, siding, roofing, etc.), combining durability, high workability and water-resistance with ease of maintenance. Today, wood composites are used in many other applications, such as disposable products, furniture, and heavy-duty objects (Hassegawa et al., 2022, 2021). Bio-composite production in Europe amounted to around 480,000 tonnes in 2020 and is expected to reach 590,000 tonnes of wood composites by 2028 (Statista Research Department, 2023).

The variable nature of wood-based composite products means that raw materials and production processes vary according to the requirements for the final product. Feedstock selection is application dependent; for example, wood fibres are used where the final product requires good mechanical properties and workability. Mitigation of the use of fossil plastics has accelerated the development and design of wood composites that contain a high percentage of bio-based raw materials, can be mechanically recycled, and are compostable or biodegradable (Hassegawa et al., 2022, 2021). To increase the sustainability of wood composites, R&D is currently focused on the fabrication of bio-based matrices instead of fossil plastics (Mäntyranta, 2020).

Wood composites such as wood chips are made with wood of various feedstock sizes
Photo © auimeesri from iStock

5.3.4 Wood foam

Cellulose from thermomechanical pulp can be manufactured into foamed structures that are rigid and have a low bulk density and high insulating capacity. The process by which wood foam is manufactured can be part of the pulp and paper value chain, which makes this product interesting to existing forest industries. Wood foam can be produced from any type of feedstock – such as wood residues from forest operations, small logs and non-commercial trees – since the component needed is cellulose fibre. Both coniferous and deciduous species are suitable feedstock. The foaming process does not require binders and resins. Wood foam is a lightweight material with several areas of application, such as packaging, thermal and acoustic insulation, composite panels and furniture (Hassegawa et al., 2022, 2021). One of the advantages of wood foam is its forming properties that allow the production of porous, 3D-shaped materials which replace the bubble warps or styrofoam used for inner-package applications (Kruus and Hakala, 2017). Commercial production of wood foams remains at a low level. However, the replacement of expanded and/or foamed polystyrene means that wood foam has good market prospects. The growth in markets is focused on the construction sector, which is the largest consumer of the material (Hassegawa et al., 2022, 2021).

5.3.5 Wood-based biochemicals

New biorefinery approaches for biochemicals boost novel value chains with new profitable products and increase the competitiveness of wood-based industries (FTP, 2020). Markets for bio-based chemicals are still slow-growing, due to their complexity that arises from the large number of possible combinations of feedstock, pre-treatment options, sugars, conversion technologies and downstream processes (Taylor et al., 2015). Bio-based chemicals can be categorised into bio-based drop-in chemicals such as ethylene and propylene, smart drop-in chemicals such as succinic acid, and dedicated bio-based chemicals such as lactic acid (Hurmekoski et al., 2018). Drop-in bio-based chemicals have easier access to markets, as they avoid the extensive and time-consuming validation of technical properties required for the commercialisation of dedicated chemicals (de Jong et al., 2012). However, the competitiveness of drop-in chemicals is weakened by comparably high running and investment costs (Kruus and Hakala, 2017).

In their role as a platform chemical provider, the wood-based industries are focusing on products that use existing industrial infrastructure (Hurmekoski et al., 2018). Pulp and paper mills are in a good position to be expanded into wood-based biorefineries. In particular, mills with bioenergy capacity enable the production of wide range of products, such as chemicals, materials and biofuels from feedstock (Mäki et al., 2021). Depending on the type of product, wood-based feedstocks in use range from sawlogs and pulp logs to wood chips, sawdust, wood pulp, tree resins and gums, in addition to recycled wood-based materials, and residues from sawmills and pulp mills (Hassegawa et al., 2022, 2021). The main route in the chemical value chain is based on production of acids and alcohols by fermenting C5 and C6 sugars contained in sawdust and chips, as well as hemicelluloses from pre-pulping liquids (Hurmekoski et al., 2018). However, sugar production in the lignocellulosic biorefineries is, in particular, a typically expensive process compared to that with sugar crops, requiring as it does a multistep process and thus pushing up both operating and investment costs (Hurmekoski et al., 2018).

To illustrate the versatility of emerging wood-based biochemicals and their applications, a set of product categories are reviewed below.

Bioethanol

Ethylene, a platform chemical for a substantial number of applications, is commonly produced from fossil-based naphtha. The bio-based substitute is manufactured by dehydration of bioethanol (Mozaffarian, 2015). Bioethanol can be produced from any type of woody biomass and feedstock, as its main component is glucose from cellulose. The fermentable sugars (e.g. xylose and mannose) from wood hemicelluloses are also suitable uses for bioethanol production (Hassegawa et al., 2021). There are two chief motivators in producing bioethanol from ligno-cellulosic biomass: to meet the European target for replacing fossil fuels for transport in a sustainable manner that avoids competition with food production, and to reduce environmental risks associated with first-generation biofuels (Cotana et al., 2014). Energy company St1 has demonstrated that production of sawdust and wood waste stream-based ethanol can be profitable, and aims to increase manufacture 15-fold. St1's wood-based traffic fuels reduce carbon dioxide emission by up to 90% compared to the fossil counterpart (Mäntyranta, 2019).

Glycols

Glycols are a group of chemical compounds widely used in industrial applications, such as automotive anti-freeze liquids, adhesives and paints. Wood-based glycols can be produced from glycerol generated as a by-product in the biodiesel process. Glycols from wood-based feedstock are considered to have substantial growth potential as a drop-in product within the value chain. The production of wood-based glycols is still at the piloting and demonstration stage. However, industrial interest is growing and an advanced biorefinery facility has been established in Leuna, Germany, where UPM produces glycols from beech wood feedstock (Hassegawa et al., 2022, 2021). The production of monoethylene and monopropylene glycols is based on catalytic conversion of sugars from sawdust and thinning wood. The UPM glycols are intended for high-volume products such as bottles, packaging, textiles, composites, detergents and antifreeze fluids, with performance and production characteristics similar to those of their oil-based counterparts (Gall and Diehl, 2022).

Lignin

A by-product of the pulp and paper industry, lignin has estimated annual availability of 50–100 Mt (Bajwa et al., 2019). Most lignin is currently used to produce steam and electricity for industry, with only approximately 5% of lignin valorised into added-value products such as phenolic resins, foams and surfactants (Bajwa et al., 2019; Hu et al., 2011). Due to lignin's substantial availability, chemical properties and price, the development of lignin-based adhesives to substitute fossil-based phenolic compounds has been the subject of intensive study (D.G. et al., 2019). It is in the chemical industry that lignin has mostly been used – as a binder and glues plasticiser, a dispersant for concrete and plasterboard, a road stabilisation material, and in animal feed applications. Today, broader industrial interest in lignin valorisation has increased, with many forest companies having their own development programmes for lignin.

Lignin's phenolic structure, which offers unique innovation potential to novel lignin-derived products, gives it scope for wider use. Swedish forest company Södra is investing in second-generation kraft lignin, which is in solid form and offers many value-added applications (Södra, 2022). Borregaard, a firm with over 90 years of experience in lignosulfonates, develops novel product portfolio based on lignin-based polymers with tailored properties (Borregaard, 2023). UMP Biofore's product range includes a portfolio of various grades of lignin. UPM BioPiva™ lignin is widely used in the plywood industry, in insulation applications and in high-pressure laminates (UPM, 2023). Lignin-based functional fillers for various rubber applications obtained through enzymatic hydrolysis of hardwood are among the products manufactured at the UPM biorefinery in Leuna. UPM BioMotion™ is a new generation of sustainable material for rubber and plastics that is ready to replace fossil-based carbon black and precipitated silica. Areas of application for wood-based fillers cover the automotive, building & construction, agriculture, packaging, transportation, personal care and electronics sectors (Gall and Diehl, 2022; UPM, 2023).

Recently, new innovative solutions based on hardwood lignin have been under industrial development. Lignin-based batteries are a revolutionary battery technology. This innovation, created by Stora Enso, aims to replace fossil graphite with hard carbon from wood-based lignin in the lithium-ion battery (Stora Enso, 2023).

Tall oil

Crude tall oil, a residue from the kraft pulping process, has an estimated global production of around 2 Mt, of which 650,000 tonnes is produced in Europe (Rajendran et al., 2016). Its production capacity is expected to increase to 2.3 Mt by 2030 (Aryan and Kraft, 2021). Tall oil has potential as a feedstock for biofuel production due to its low oxygen content and minimal need for process treatments (Mäki et al., 2021). The value of the crude tall oil can be added by fractionating it into several different chemical compounds. One of these derivatives is naphtha, which can be used in the production of biodiesel and bioplastics (De Bruycker et al., 2014; Mäntyranta, 2020). In addition, crude tall oil can be used to produce (among other chemicals) ethylene, which is a platform chemical for several applications, including bio-based plastics (De Bruycker et al., 2014).

5.3.6 Nanocellulose

Nanocellulose has been shown to have a broad range of excellent physical, chemical and biological properties, which have engendered a great deal of scientific and industrial interest towards nanosellulosic materials. Nanocellulose can be obtained from different plant-based feedstock, but the most used source is wood: mainly soft and hardwood pulps (Reshmy et al., 2020). The extraction and fabrication of cellulose nanofibrils is a complex, multistage process that involves mechanical grinding and microfluidisation, as well as chemical and/or enzymatical treatments. Due to the fibril networks of high surface area and high density of reactive hydroxyl groups, the inherent macroscale fibre properties are enhanced at the nanoscale, giving the material excellent translucent and/or transparent properties and film-forming characteristics, as well as unique water interaction properties, high mechanical strength, and scope for modification (Mautner et al., 2018).

Due to its unique functional properties, nanocellulose has a broad range of applications. Its availability and good mechanical properties have resulted in nanocellulose being commonly used in the pulp and paper industry (Balea et al., 2020). Nanocelluloses can be employed in the production of paper as a substrate material, or as an additive or in coatings. Cellulose nanofibres – which possess abundant wet and dry strength, optical clarity, high thermal stability, low thermal expansion, surface smoothness, tensile strength, and good water barrier properties – are the most widely used among other nanocellulose materials in the paper industry (Reshmy et al., 2020). Coatings improve the properties of food and beverage packaging materials. In flexible packaging, for example, coatings include several thin layers varying in thickness from tenths of nanometres to a few micrometres. Nanoscale cellulose products provide an excellent alternative to oil-based coatings and thin layers used in packaging (Reshmy et al., 2020). Nanocellulose's good barrier properties against gases and grease further boosts the usage of this material in food packaging (Reshmy et al., 2020; Vartiainen et al., 2016; Willberg-Keyriläinen et al., 2017). In recent years, cellulose nanocrystal (CNC) has attracted growing interest as potential additives and reinforcing materials in cement and concrete, due to its low density and high tensile-strength properties, which strengthens the microstructure of cementitious material. Added-value uses for nanocellulose include cosmetic, medical, electronic and photonic applications. The attractiveness of CNCs in electronic applications is due to the ease of modification, dielectric and piezoelectric properties of the material (Reshmy et al., 2020).

5.3.7 Bioenergy and biofuels

The global energy supply system is currently in a state of rapid transition from fossil to non-polluting and non-depleting energy systems. Currently, bioenergy is the world's major form of renewable energy. For example, wood-based bioenergy is expected to be a vital part of the Finnish energy system in 2035 (Arasto et al., 2021). In general, the pulp and paper industry in Nordic countries is strongly associated with bioenergy. The mills are also producing heat and power for external use, as for example by municipalities (Mäki et al., 2021).

Bioenergy is a mature technology with improved efficiency. However, there is still room for improvement in reducing dry-matter loss in the supply system and storage. The electricity sector is undergoing rapid decarbonisation due to various cost-efficient factors (Arasto et al., 2021). One essential end use of bio-based chemicals is that of liquid fuels for transport. Demand for advanced biofuels is chiefly driven by international and national policies (Hurmekoski et al., 2018). Biomass and biomass residues can have a significant role as energy sources suitable for drop-in use, such as bio-coke, biogas and liquid biofuels for long-haul transport. These energy sources, which can already be produced in large quantities, are able to be utilised in the existing infrastructure (Arasto et al., 2021). According to Deane and Pye (2018), the tall oil technology route to renewable diesel seems to be an economically competitive means of producing biodiesel. However, given that it is a minor by-product from kraft pulping, the available volume of crude tall oil remains small, which affects its use as a feedstock for biodiesel. This also applies, to some extent, in the production of other fuels and chemicals, which are constrained by the availability of by-product flows from sawmills and pulp mills, although some processes involved may also employ forest residues or small-diameter wood (Hurmekoski et al., 2018).

Biomass use combined with carbon capture and storage (CCS) offers the potential for a technological means of removing carbon dioxide (CO2) from the atmosphere. The advantage of Bio-CCS, as it is called, lies in its combining removal with energy or product generation, thus creating positive revenue streams for the solution. The need for these ready-to-be-deployed technologies will be emerging before 2040. Initial applications of this technology are expected to be seen prior to 2030, especially in relation to biogenic fractions of waste (Arasto et al., 2021).

5.3.8 Building with wood

The overall construction sector is responsible for approximately 40% of global energy-related CO2 emissions due to extraction, processing and energy-intensive manufacturing of construction materials and products. Wood construction (building with wood) has gained an increasing share of the construction sector, given that bio-sourced materials and products contribute largely to the decarbonisation of the sector. Europe is a leader in the development of new wood-based building elements, products, materials and solutions aimed at reducing CO2 emissions and achieving net-zero targets (CEI-Bois, 2020).

Building with wood has gained an increasing share of the construction sector
Photo © Maudib from iStock

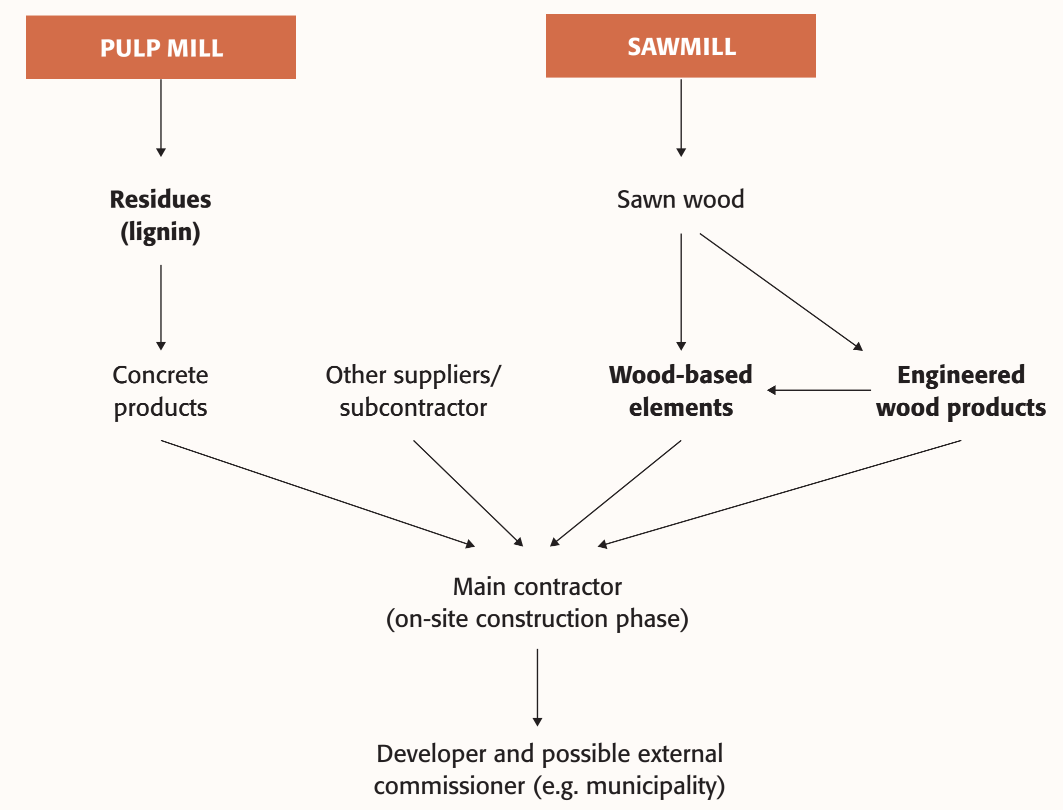
Innovations of the last 25 years have given rise to a new generation of high-performing elements already on the market, with more continuously being developed. Relevant 'game changers' here include the following: the introduction of cross-laminated timber (CLT); laminated veneer lumber (LVL); mixed elements with other materials; load-bearing panels and boards as well as prefabrication solutions allowing designers and architects to open up new pathways for short-term, aesthetic and high-performing buildings. Specifically, prefabrication construction is ushering in a new era as information and communication technologies allow elements, materials and structures to be designed, used and reused in a new way, and will boost the circular-bioeconomy approach. New business strategies are emerging that have been positively tested and proven in other areas. They are binging positive changes to the wood construction sector, including lean management for design and production of buildings, right through from the idea to the construction site (CEI-Bois, 2020). Research literature suggests an almost unanimously positive outlook for modern wood construction (Figure 25) (Hurmekoski et al., 2018). Wood has traditionally been used to build single-family, agricultural and storage buildings. However, the move towards industrial prefabrication and standardisation of wood construction in Europe and North America has made it more straightforward to utilise wood in large-scale construction as well. In design and industrial prefabrication, a shift is being seen from on-site construction to off-site manufacturing of elements and components, i.e. combining several work phases in a single off-site location, which can result in productivity benefits (Malmgren, 2014). Engineered wood products (EWPs) that have emerged over the last few decades further enhance the competitiveness of wood in multistorey buildings and industrial units. EWPs can thus directly compete with steel and concrete, due to their having more homogeneous technical properties than sawn wood in terms of load-bearing capacity and dimensional stability (Hurmekoski et al., 2018).

Building and living with wood is an important driver of raw-material availability for pulp and paper and for emerging industries, as sawmilling generates raw materials for these industries (wood chips, bark, sawdust and forest residues).

EU-level harmonisation of regulations, building codes and standards is among the most pressing needs in order to boost the role of wood and bio-based materials in the construction sector. EC services launched a New European Bauhaus initiative to facilitate the transformation of habitats into a healthier, socially balanced, and integrative living space that will contribute to achieving policy goals set by the European Green Deal (Chapter 3). It is estimated that around 70% of the actual building stock in Europe needs to be refurbished for energy efficiency and to improve the indoor climate. The Renovation Wave strategy targeting Europe's building stock should be seen as harbouring tremendous potential for wood and bio-based materials, approaches and solutions (Cazzaniga et al., 2022).

Figure 25

Construction value chain



Source: Hurmekoski et al., 2018

5.4 Outlook from a circular and sustainable forest-based bioeconomy perspective

Forest products, including wood and wood products, can contribute to climate change mitigation in that these harvested and processed items store carbon, substituting for greenhouse gas (GHG) emission-intensive products and energy.

Therefore, smart and sustainable use of wood can be viewed as one of the drivers of the green economy that will help achieve policy goals set by the European Green Deal, the EU's 'Fit for 55' climate package, the New EU Circular Economy Action Plan, the new EU Biodiversity Strategy, the new EU Forest Strategy, the New European Bauhaus Initiative and the European-wide Renovation Wave strategy, as well as the overarching UN Sustainable Development Goals 2030 (Chapter 3). The transition towards a circular bioeconomy will require integrative cooperation among all stakeholders and actors. New business strategies call for a change in the mindset of decision-makers within the public, private and societal sectors (Partanen et al., 2020).

In some North and Central European countries (such as Finland, Germany, Austria and Sweden), both the economy and general well-being are strongly based upon the sustainable use of forest biomass. These countries have developed new bioeconomy strategies and action plans to increase the value of wood-based products (Bioökonomie Austria, 2023; Chapter 3).

Global demand for wood as a raw material is increasing, as the advancement of novel wood-based innovations is highly dependent on the availability and quality of the wood material. According to the Finnish Forest Industries Association, the future need for wood mobilisation is difficult to estimate as the industrial requirement for wood strongly depends on global markets and demand (Niemi, 2023). Furthermore, the current debate on the status of forest carbon sinks in standing and old-growth forests, as well as related biodiversity and climate regulatory actions (Chapter 3), might well have an impact on future wood flows and their use in the industry.

Diversified industrial use of wood is a growing global trend, as is the change in market structure within the forest sector and industries that use wood. The role of emerging innovative wood products – such as materials for construction, textiles, chemicals, bio-based plastics, biofuels, food additives and pharmaceuticals – is increasing in the forest sector portfolio. According to Stora Enso, forest companies are likely, going forward, to diversify their production to include added-value products, very much prioritising the product portfolio instead of traditional bulk production (Niemi, 2023).

The major obstacles to the market uptake of emerging wood-based products are the slow pace of change of linear business models towards circular, less rigid economic and energy structures, and traditional production systems. Furthermore, the conservative nature of industries and consumers' behaviour patterns is slowing down the transition to a circular bioeconomy. In most cases, traditional fossil-derived products can be substituted by bio-based alternatives. However, fossil-based production systems benefit from economies of scale and scope, as well as evolution of technologies and knowledge of market penetration, which have resulted in a 'lock-in' into fossil-based production structures and demand patterns. The lack of capital funding and long investment cycles in the emerging forest-based bioeconomy sector hinder the market penetration of new innovations. Industrial ecosystems with both large companies and small and-medium-sized enterprises (SMEs) are needed for a successful forest-based bioeconomy (Rönnlund et al., 2014). Both today and during the next decade, wood-based industries are and will be facing challenges in the supply of wood across Europe. Efficient harvesting operations (both motor-manual and machinery based) will become a crucial factor alongside transport and logistics costs. Storage capacities and time-to-transformation are putting companies under pressure due to partly unpredictable weather conditions and secondary effects of climate change.

In conclusion, it is clear that it is becoming essential to valorise research, new knowledge and professional expertise, as these play a crucial part in identifying the potential role of the forest-based bioeconomy in sustainable growth and societal well-being. There will also be a paradigm shift in future needs for basic research, as well as in innovation actions, as these are having to focus on the holistic and resource-efficient use of whole wood materials, including side-streams and waste streams. Both circularity and cascading aspects give rise to the wider framework and conditions influencing wood-based industries. They need to be considered in novel product innovations, processes and forest-based services. In addition to technological advances, new circular operational and business models and co-creation practices provide new pathways for forest industries. Furthermore, the knowledge gap related to different displacement factors concerning emerging wood products needs to be narrowed.

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PART 2

PRACTICAL IMPLICATIONS AND RESPONSE OPTIONS FOR MULTIPLE ACTORS

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Chapter 6

Synthesis of factors and future scenarios

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6.1 Analysis of factors affecting wood supply in Europe

The previous topic-based chapters (2–5) identify a range of environmental, political, socioeconomic and technological factors affecting the supply of wood in Europe (as briefly summarised in Table 22). Scientific and practical knowledge concerning each one of these key factors, and their impacts on the European wood supply, is analysed in the following sections.

Table 22

Key environmental, political, socioeconomic and technological factors affecting wood supply in Europe

Factors impacting wood supply in Europe			
Environmental	Political	Socioeconomic	Technological
Forest types and growth	EU and national forest-related policies and laws	Forest ownership	Innovative wood-based technologies
Climate change	National forest policy priorities	Demographic developments	Emerging wood-based products
Forest management	Forest property rights	Market trends	
		Geopolitics and international trade	

Source: Produced by Sotirov, 2023

6.1.1 Environmental factors

Chapter 2 shows that it is environmental factors, such as climate change, that have the most direct influence on wood supply as they affect forest composition, structure and productivity. The reviewed scientific evidence points to an increase in temperature along with changing patterns of precipitation in the future, which is expected to have strong effects on tree growth and tree mortality. Available practical knowledge also reveals that forest management cannot control tree mortality caused by disturbances, including droughts, storms, bark beetle and fires, all of which are expected to increase during the 21st century and cause losses in wood production.

As such, the future supply of wood remains uncertain and dependent on different climate change trajectories and future forest management options. If global warming remains under 2°C, business-as-usual (BAU) forest management would maintain growing stocks and wood harvest volumes, while salvage harvests in spruce forests would still increase significantly. At global warming levels of between 2°C and 3°C, a BAU approach could not maintain stocks, and wood harvests would decrease. If climate change-adapted forest management is widely applied, growing stocks and wood harvests could be stabilised, although at lower levels than under current practices. At higher global warming levels of 3°C and beyond, wood production is likely to decrease in absolute terms.

It is important to note that the level of future global warming depends on greenhouse gas (GHG) emissions and concentrations. In turn, GHG emissions and concentrations are determined by political, socioeconomic and technological developments over time in many societal domains such as energy, transport, housing and agriculture. To explore these uncertain and complex developments, the Intergovernmental Panel on Climate Change (IPCC) devised what it terms Shared Socioeconomic Pathways (SSPs), which are used by scientists and stakeholders as scenarios of projected socioeconomic global changes up to the year 2100 (Riahi et al., 2017, see Chapter 2). Informed by the SSPs, the Representative Concentration Pathways (RCPs) were developed as trajectories of GHG concentration (not emissions). The RCPs describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted over time.

6.1.2 Political factors

Chapter 3 shows that political factors such as EU and national forest-related policies, laws, priorities and property rights have a major influence on wood supply. Currently, a lack of coherence between many EU and national forest policies results in vertical (i.e. across levels of governance) and horizontal (i.e. across sectors) policy trade-offs. Scientific evidence, along with practical knowledge, reveals that conflicting EU and national policies and laws on biodiversity conservation and climate mitigation constrain wood supply. While some policies prioritise forest biodiversity conservation and carbon storage in standing forests, other policies support wood production for construction, bioenergy use and carbon storage in harvested wood products. Institutional differences in property rights of forest owners and managers are evident in Europe, which also has an impact on wood supply.

At the national level, diverse priorities in forest and forest-related policy frameworks impact forest management and wood supply. These priorities range, among various other aspects, from wood production and bioenergy use in North Europe, to multiple-use forestry integrating wood production, biodiversity protection, and climate adaptation in Central and West Europe. Additionally, implementation challenges could arise across EU countries, with some needing additional policy and legal changes.

Therefore, the future of wood supply partly depends on policy, legal and institutional developments at both EU and national levels. Potential future scenarios include environmentally friendly policies that prioritise biodiversity and climate considerations, leading to restrictions on wood supply and changes in wood composition. In contrast, bioeconomy-friendly policies could prioritise wood use for material and energy purposes by supporting a management approach oriented to the production of wood.

6.1.3 Socioeconomic factors

Chapter 4 shows that socioeconomic factors such as forest ownership, demographics, and geopolitical and trade developments have also an important influence on wood supply, both directly and indirectly. The review of information revealed a diverse forest ownership structure in Europe, where 56% of European forests are privately owned by individuals and families with properties smaller than 10 ha. The heterogeneity of private forest owners (PFOs) – including non-traditional, passive or absent owners – has shifted forest management objectives away from wood production and towards multiple or environmentally oriented objectives. Profit maximisation is no longer the main motivation for many PFOs, since social and personal factors play a more significant role in wood harvesting decisions.

The scientific review also shows that the objectives of forest owners and the management practices they adopt are diverse, ranging from profit-oriented intensive forestry to environmentally oriented and close-to-nature management practices. Future demographic developments outlined in the review highlight the trend towards a stagnating, ageing and urbanised European population. Projections indicate a peak population of 453 million in 2026, decreasing to 448 million by 2050, and a further decrease to 420 million by 2100. The urbanisation rate is likely to increase in tandem with old-age dependency and rise from 32% in 2020 to 52% by 2050, and to 56% by 2100.

Geopolitical and trade developments signal a shift away from BAU globalisation towards a regionalisation of economic production, trade and consumption of wood and other commodities. The EU's ban on wood imports from Russia and Belarus, coupled with the introduction of its Deforestation-Free Regulation, signals a move towards higher standards for legality and sustainability. Geopolitical tensions and uncertain trade relations between Western countries and BRICS (Brazil, Russia, India, China and South Africa) member nations are leading to regionalisation in global wood supply chains, particularly in North America, Europe, and Asia.

If these demographic, geopolitical and trade trends persist in the future, they will pose significant challenges for wood supply on the EU market. If population in Europe remains stagnating, ageing and urbanised, then domestic wood supply on the EU market will decline due to the decrease of available labour in the industry sector, the number of forest owners interested in wood production, and an overall reduction of market demand by EU consumers. Additionally, higher energy costs would decrease competitiveness of European forest sector industries and businesses, further increasing competition for woody biomass between material and energy uses.

6.1.4 Technological and market factors

Chapter 5 shows that technological and market factors can influence the supply of wood. Global market trends indicate a growing demand for both short-lived and long-lived wood-based products. Wood utilisation saw a gradual increase during the period 2009–2017 and is expected to grow exponentially by 2030. The European forest-based sector's strategic vision for 2040 is to increase the added value, circularity and diversification of production technologies for producing new wood products.

Newly emerging technologies include digitisation, artificial intelligence, advanced timber harvesting, innovations in logistics, and developments in industrial biotechnology and synthetic biology. Together with circularity and diversification of biomass utilisation, these new technologies are expected to pave the way for increasing added value, and for supporting a sustainable forest-based bioeconomy, by changing the market structure and increasing competitiveness.

Market forecasts highlight a rapid expansion of wood-based engineering products (e.g. cross-laminated timber (CLT)2) and textiles, stable growth for wood-based packaging material, bioenergy, biofuels and biochemical products, and slower growth for traditional wood products such as sawn wood and veneer. Demand for graphic-paper products is expected to decline, while other paper products may experience stable market demand. The importance of the role of novel and innovative wood-based products and new circular business strategies depends on a range of environmental, political and socioeconomic factors, including secured sourcing and mobilisation of wood, overcoming economic reliance on fossil fuels, guiding the complexity of the regional policy and legal framework across Europe, addressing environmental issues and overcoming technological limitations. Meanwhile, technological limitations involve transportation distances and logistics plans, as well as a need for technology integration.

The transition to sustainable growth is politically, economically and technologically supported, and can serve as the 'green engine' for a circular bioeconomy. Diversification, innovative product portfolios and new value chains can create added value for the wood-based sector. Collaboration and joint efforts at various levels are crucial to secure wood supply, thus ensuring the permanence of the wood-based sector going forward.

Forests in Europe face an uncertain future that could materialise in various future scenarios
Photo © Nelson Grima

6.2 A forward-looking view: future scenarios

6.2.1 Why future scenarios?

Forests are characterised by very long life cycles and are part of complex ecological and socioeconomic systems with many unknown interrelationships. As such, both environmental (e.g. climate change, species composition) and socioeconomic factors (e.g. forest ownership) have significant impacts on forests. Complexity and uncertainty in forests are further amplified by factors such as demographic changes (e.g. population growth, urbanisation, ageing), economic developments (e.g. market growth and decline, supply, demand, prices), political changes (e.g. policy development and implementation), and technological developments (e.g. new products and techniques). While trees grow, societal needs change over time and space. However, most of the future conditions and developments are still unknown today.

An approach based on thinking in terms of future alternatives ('what if' future scenarios) was used in the present study (see key definitions in Box 3). A scenario-based synthesis helps link the foreseeable developments involving the different factors by means of coherent narratives about contrasting 'forest futures'. This is achieved by mapping the main findings of the synthesis of individual factors on the main narratives of the IPCC-defined SSPs. That is, the SSPs' scenario narratives were used as a starting point, and were further developed and adapted in keeping with the insights gained from the analysis of information presented in Chapters 2–5. Although scenario narratives are hypothetical outlines and the product of guesswork, and as such may never materialise, they offer stakeholders both an opportunity to think about potential developments, and information to anticipate reactions within a defined context.

A systematic exploration of the different forest futures is needed, since industries and business, forest owners and forest managers, political decision-makers and other stakeholders (e.g. non-governmental organisations (NGOs), scientists) very often operate within different timeframes. For example, forest management planning usually looks 10 years ahead, while operational and financial planning in forest- and wood-based industries is often carried out on an annual – or even on a daily – basis. EU strategies and policy targets (e.g. biodiversity, climate and bioenergy goals for 2030, net-zero goals for 2050), including financial planning, refer to periods between 10 to 30 years in length. Meanwhile, political and sometimes administrative turnover (and hence, policy changes) happen approximately every four years.

Box 3

Scenarios: Key definitions and methodology

Within the context of this study, scenarios are logical storylines and coherent narratives describing alternative environmental, socioeconomic, political and technological developments over time. The scenarios describe an end-state in the foreseeable future, and how this end-state comes about through specific developments. They place emphasis on revealing what key influencing factors are driving which developments, and how the future could evolve differently based on interactions among these factors. As a basis for building these scenarios, knowledge and information on factors influencing future developments, trends and hard-to-predict events is collected.

It is important to note that the scenarios subject to this study only describe a hypothetical future and not the most likely scenarios that could materialise. In reality, some of the developments described in the scenarios could occur fully or partially, while others may not happen at all. Future realities will most probably constitute a mix of what the scenarios describe.

6.2.2 Future scenarios for wood supply in Europe

Scenarios provide a structure and language for ongoing dialogue about assumptions, emerging trends, potential surprises, diverse viewpoints, and long-term objectives and strategies. Conducting these discussions at various organisational levels, and with stakeholders, allows for the collection and integration of the most valuable insights from individuals with diverse backgrounds and perspectives. These insights inform on potential positive and negative effects, and can then be incorporated into decision-making and planning processes.

Devising scenarios provides a way of thinking about the future, especially when there are uncertainties and complexities in strategic decision-making. Based on information about the past and present, scenarios are used for building coherent stories about the future. Organisations use scenarios to navigate their strategic options in complex and uncertain contexts, especially when decisions involve significant investments, or have long-term consequences. Building on the IPCC-defined shared socioeconomic pathways (SSPs) and the IPCC-adopted Representative Concentration Pathways (RCPs) (see Chapter 2), and informed by the qualitative and quantitative information in the topic-based Chapters 2–5 and the synthesis described in Chapter 6, three future scenarios for wood supply in Europe were developed. An overview of these scenarios is presented in Table 23, with the individual scenario narratives described in Boxes 4, 5 and 6 below.

Table 23

Overview of scenarios

	Scenarios		
Factors	'Environmental sustainability first'	'Bioeconomy in a divided world'	'Fossil economy first'
Climate change	Low (below 2°C)	Medium (2–3°C)	High (above 3°C)
Policy factors	Priority of environmental policy at EU and national level	Environmental policy takes priority at EU level, but bioeconomy policy takes priority at national level	Incoherencies between EU and national environmental and economic policies
Market and technological factors	Low economic growth in Europe, strong trade within BRICS countries	Knowledge-based circular bioeconomy	Energy-intensive fossil economy
Geopolitical factors	Low energy and bioeconomy intensity worldwide	High priority given to regional green energy, and to bioeconomy self-sufficiency, in Europe, and rivalry with 'Global South'	Global push for political and economic development
Demographic factors	Low population growth and urbanisation in Europe and worldwide	Low population growth in Europe and 'Global North', high population growth in 'Global South'	Low population growth in Europe, high population growth in 'Global South'
Forest management	Ecosystem management approach	Wood use-oriented sustainable forestry	Forest calamities management

Source: Produced by Sotirov, 2023

Box 4

Description of scenario 1 'Environmental Sustainability First'

Supported by an environmentally concerned, ageing, stagnating and urbanised society, the world shifts toward environmental sustainability, low material growth, and low resource and energy intensity. Low GHG emissions, after implementation of the Paris climate policy goals (including in the Land Use, Land Use Change and Forestry (LULUCF) sector), lead to a lower temperature increase of up to 1 to 2°C in Europe. EU and national forest conservation and climate policy targets are implemented as a priority. This leads to effective conservation of 30% of all forests, including 10% of strictly protected forest areas, the effective conservation of primary forests, clearcutting bans, close-to-nature forest management, and biodiversity-friendly restocking on the 70% of remaining forest area by 2030–2050. Biodiversity-friendly climate policy goals of carbon reduction by 55% until 2030 and carbon neutrality (net zero) by 2050 are achieved by capturing carbon in standing/old-growth forests, reduction of wood harvests for material and bioenergy use, and supporting climate-resilient mixed and deciduous forests, among other actions. Facilitated by passive (non-traditional) private forest owners with urban values and lifestyles, and law-compliant public forest managers, there is a reduction in forest areas available for wood supply and the share of softwood from coniferous monocultures, whereas the share of hardwood from mixed or deciduous forests is increased. Imports of woody biomass are restricted, as Russian and tropical exports are redirected to China. A global move towards increased self-sufficiency and sourcing close to home, in conjunction with wood scarcity, are forcing an efficient, cascading use of woody biomass and increased usage of domestic hard wood.

Building on and further developing the IPCC-defined SSP1; direct link to RCP 1.9–2.6

Box 5

Description of scenario 2 'Bioeconomy in a divided word'

At the global level, nationalism, competitiveness, security issues and regional conflicts push countries to shift policies toward national- and regional-energy, food and biomass security, and to neglect global environmental policy issues, including deforestation and forest degradation. Population growth is low in high-income countries and high in mid- and low-income nations. After global emissions peak around the year 2040 and then decline, intermediate global warming leads to a temperature increase of 2°C and precipitation gains of 100 mm/year in North/West Europe, and to a temperature increase of 2–3°C and precipitation loss of 400 mm/year in Central/South/East Europe. While forest conservation and climate policy remain a priority at EU level, wood-oriented bioeconomy, and climate and bioenergy policies are implemented as a priority at national level. The combined effects of climate change and policy result in shifts towards the spread of areas with less productive deciduous forests in Central/South/East Europe, and in the increase of areas with faster-growing coniferous forests in North/West Europe. Prompted by EU political impetus vis-à-vis a green economy, and increased renewable energy self-sufficiency, the circular and sustainable forest-based bioeconomy in Europe is incentivised through knowledge, innovation and investments after some years of regional rivalry between Europe and other global regions. Forestry, wood, wood-based materials, renewable energy, new textiles, food additives, chemicals, pharmaceuticals, cosmetics and other emerging industries work together towards high-value use of (both primary and secondary) woody biomass.

Building on and further developing the IPCC-defined SSP 4–5; direct links to RCP 4.5

Box 6

Description of scenario 3 'Fossil economy first'

A global push for socioeconomic development through intensive fossil energy and resource use leads to a dramatic rise in global GHG emissions by 2100, and temperature increases in Europe of between 2–3°C (North/West) and 3–5°C (Central/South/East). Despite favourable growth conditions caused by the warming climate in some European regions (North/Central), frequent extreme weather events and natural disturbances (e.g. wind, fire, drought, insects, pathogens) cause abrupt changes in forest structure. Oak species occupy 30–40% of total forest area, while the area of coniferous tree species (e.g. spruce) shrinks by 50% compared to 2023. EU and national forest policy incoherence cannot solve conflicts between conservation and wood use. Unlike the growing population in the 'Global South', stagnating population growth, ageing and urbanisation in Europe negatively impact (rural) labour and the willingness of private forest owners to harvest wood. Imports of wood shrink after Russian and tropical exports are redirected to China. These developments prevent the circular bioeconomy from growing, and pose serious challenges for the supply of intra-EU softwood – not counting the short- to medium-term increased supply of wood from salvage logging. Elevated energy prices further decrease the profitability of energy-intensive forest industries that do not produce sizeable side-streams useable for energy. The consequences are a decline of wood-based industries in Europe, with some facilities reducing production while others relocate or close down.

Building on and further developing the IPCC-defined SSP 4–5; direct links to RCP 4.5


7

Chapter 7

Stakeholders' perspectives on the consequences of future scenarios

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7.1 Introduction

This chapter summarises possible consequences of each scenario as perceived by (1) wood-based industries, (2) forest owners and forest managers, and (3) political decision-makers and other stakeholders. In the context of each scenario, consequences were identified and further defined by key informants and representatives of wood-based industries, private forest owners (PFOs) and public forest managers, forest policymakers, and by social and natural scientists, all of whom were attending a science-business-policy workshop held in Vienna on 15–16 June 2023. Transdisciplinary know-ledge was generated by moderated participatory World Café focus group discussions. A synthesis of the scientific and practical knowledge (Chapter 6) was provided as input for the focus group discussions. Each World Café discussion (one for each scenario) had three rounds (involving rotating participants), in each of which the participants were asked to discuss the short- and long-term consequences of the various scenarios. In all World Café focus group discussions, securing the availability of wood while maintaining other key forest ecosystem services was formulated as a desired state in the future.

World Café discussions about the future of wood supply at the TEAMING UP 4 FORESTS Think Tank 2023
Photo © Doris Unterrainer

7.2 Consequences from Scenario 1 'Environmental Sustainability First'

(see Box 4 for narrative description)

7.2.1 Industry and business perspective

Industry relocation
Most participants agreed that Scenario 1 'Environmental Sustainability First' would have huge impacts on wood supply if the EU's nature and climate policy targets for 2030 and 2050 are met. Due to the increasing lack of sufficient wood quantities and the insufficient market availability of wood in terms of specific qualities (hardwoods), a significant increase in production costs is to be expected. One foreseeable consequence would be that the larger forest-based industries in Europe might relocate all or parts of the production chains outside the EU, scaling down production activities in the EU market. Relocating EU industries to other continents would be motivated by the thought of securing raw-material and wood supply, reducing production costs and maintaining a competitive advantage in the global markets. This industry relocation would result in a loss of competitiveness and economies of scale in the EU. Globally, relocation of EU industries would lead to industrial investments in other world regions with potentially higher emissions from deforestation and

forest degradation. It would also result in higher pressure on forests, as well as the establishment of new tree plantations in other parts of the world, a development labelled as 'ecological colonialism'.

Regional industry consolidation

Under this scenario, regional consolidation would be expected on the EU market, where mainly regionally and locally producing and sourcing industries dominated by small and-medium-sized enterprises (SMEs) would survive and continue their business operations. These remaining regional SMEs would only be able to supply a smaller quantity of wood products, which would not cover the overall EU demand. The scarcity and changes in quality of the raw material (more hardwood than softwood) would lead to higher prices if consumer demand in the EU remained at today's level.

Industry transformation through diversification and added value

Due to the foreseen scarcity of wood under this scenario, many European wood-based businesses might implement transformative change processes, which would entail the broadening and diversifying of products, focussing on new added-value products of increased quality and prices that are made from a diversity of hardwood species (e.g. oak, beech). In addition, industry transformation in Europe would embrace innovations in the forest-based bioeconomy, including nanotechnology, bio-based textiles, bio-based chemicals, etc. An important part of this transformation would involve shortening and decarbonising wood value chains by, for example, recycling products and using cascading systems that prioritise the material use of wood over bioenergy use. In order to mobilise wood from close-to-nature forest management (as opposed to intensive forestry methods widely used today), industries and business would offer a full service, including the sustainable harvesting, transport, and marketing of wood, across properties to achieve economies of scale.

7.2.2 Forest managers' perspective

Socioecological shift in forest management

Under this future scenario (scenario 1), the main role of sustainable forest management would not be to supply wood for the industry, but to secure other key forest ecosystem services demanded by society, such as biodiversity conservation, carbon sequestration, water protection, recreation and spiritual values. This would result in changes to current forest management practices, including a shift to close-to-nature management approaches with more natural regeneration and less tree planting, avoidance of clearcutting and other intensive forestry practices (e.g. soil treatment, pesticides), and embracing adaptive forest management with more forest set-asides and old-growth forests to create diverse, multiaged forest structures and mixed-species forests, which can help to increase the resistance and resilience of forest ecosystems to climate change. These shifts tend to require a longer-term process after substantial investment to change current harvesting and silviculture systems, as well as investing in the education of forest owners and forest managers.

Economic return and shift in forest management

In contrast to the previous views, it could be that some forest owners and managers would choose to intensify forest management in order to continue satisfying economic objectives of wood production. This would imply an increase of productivity in forests outside protected areas. Some forest owners and managers might also respond by expanding the forest area through afforestation of new areas where faster-growing tree plantations would not be under nature conservation regimes, and could be intensively managed.

7.2.3 Policy and society perspective

Industry-supportive regulatory policy changes

Some national policymakers and administrations could challenge the ambitious EU nature conservation and forest sink targets during policy implementation by emphasising rules that boost wood supply and the bioeconomy. Consequently, expansion of nature conservation and forest sink targets would be cut short, and more flexible implementation of targets for protection of forest areas would be promoted. This would call into question the effectiveness of strictly protected forest areas, while supporting forest management approaches. National policy changes would aim to meet biodiversity and climate targets by actively managing forests, including encouragement for sustainably certified wood harvesting from protected areas to achieve higher prices on the market. If both EU and national nature conservation targets are to be strictly complied with, some national policymakers and administrations may try to achieve these targets by officially designating as protected those forests that are either already strictly protected or effectively protected (i.e. inaccessible due to location in steep terrain or wetlands, unproductive, etc.)

Economic incentives from public funding, market-correcting rules and new markets

If forest conservation and forest sink targets are to be met under this scenario, public policy would need to financially compensate forest owners and businesses for reducing wood supply, which would require substantial and continuous subsidies (up to 10 times higher than today). These subsidies could take the form of either public payments for ecosystem services to incentivise the adoption of close-to-nature forest management, or compensation for income losses due to forest set-asides and reduction of wood harvest (e.g. through quotas). Substantive and continuous amounts of public funds may not be available to cover the costs of socioecological forest sustainability. Increasing public taxes to cover the costs might not be feasible, as this could conceivably lead to societal conflicts in EU countries. Hence, the funding could come from higher wood prices and/or development of new markets for forest ecosystem services (e.g. carbon, availability of 'funeral forests', health benefits).

Societal and consumer change

It is widely perceived that this scenario will only transpire if society accepts the profound socioecological transformation involved and is willing to pay for the costs. There would be a need to learn to consume less wood and pay more for it (and to accept this), and the progressive urbanisation of society would reduce non-state forest owners' knowledge and capacities regarding management of their forests.

7.3 Consequences from Scenario 2 'Bioeconomy in a Divided World'

(see Box 5 for narrative description)

7.3.1 Industry and business perspective

Better knowledge needed

The expert discussions were based upon the uncertainty of how much wood will be available and supplied to wood-based industries under this scenario. Improved understanding of the meaning of forest biodiversity conservation and forest sink targets for industry would be needed, factors which will affect wood supply in the future. Defining and measuring wood consumption per capita in Europe would be an important step for adaptive planning.

Industry transformation by innovation towards circularity and decarbonisation

New strategies and approaches for adaptation by forest industries and businesses would be needed under this scenario, for example by integrating a circular-economy model. Under this model, in addition to forest resources, existing materials would become an immense source of resources by means of reuse and recycling, as well as through production of bioenergy at the end-of-life cycle ('cascading use'). This could be coupled with strategies to reduce raw-material input while increasing output of added-value products ('producing more – with less'). Decarbonisation of wood-based industries, and of the chemical and energy sector, would be necessary to achieve this scenario, which would increase competition for wood biomass with regard to biomaterials and bioenergy. Under this scenario, emphasis will be placed on the overall reduction of energy consumption in all aspects of production, consumption and everyday operations.

Industry support for European and global bioeconomy cooperation

Despite current and future geopolitical tensions, there is a need for the wood-based industry to foster cooperation at both European and global level. Harnessing the EU's political impetus vis-à-vis the green economy could help to overcome regional rivalry between Europe and other global regions. Forestry, wood, wood-based materials, renewable energy, new textiles, food additives, chemicals, pharmaceuticals and cosmetics, as well as other emerging industries, would need to work together across countries in Europe and beyond to create a high-value use of woody biomass.

7.3.2 Forest managers' perspective

Bioeconomy-supportive forest management

Both forest owners and industries will need to adapt to the disruptions and opportunities of this scenario by establishing stronger collaboration, by selecting and adapting to appropriate tree species, and by implementing forest management practices that support a circular, forest-based bioeconomy while helping to adapt to climate change and producing bioenergy.

7.3.3 Policy and society perspective

Cross-sectoral policy integration

There is a need to reduce complexity and trade-offs between EU and national policies by improving cross-sectoral and multilevel policy integration. This need becomes particularly evident under this scenario. Harmonisation and standardisation of laws and policies would allow the creation of new markets and business collaboration for a circular forest-based bioeconomy.

Forest bioeconomy-supportive policies and society

Efforts aiming at paradigm changes would need to take place in all industrial sectors and in society at large, which would benefit from more clarity, stability and acceptance regarding a circular, forest-based bioeconomy. This would secure investments and operations to transform the wood-based sector into a circular-bioeconomy hub in Europe. Existing innovations would then be widely applied on the market by means of sufficient investment.

Learning and cultural paradigm change

A circular economy would require a paradigm change in the mindset of industries and businesses, forest owners and managers, as well as policymakers and stakeholders. This could be achieved by fostering new educational programmes and research, highlighting the importance of changing managerial strategies, and viewing the wood-based sector as part of a larger system. This also emphasises the need for long-term planning, collaboration, adaptation to disruptive changes, seizing of opportunities, and a holistic approach to addressing challenges faced by the wood-based sector.

Exchange of stakeholder views in small group discussions at the TEAMING UP 4 FORESTS Think Tank 2023
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7.4 Consequences from Scenario 3 'Fossil Economy First'

(see Box 6 for narrative description)

7.4.1 Industry and business perspective

Industry competition and relocation

In view of the expected changes in species and productivity, import/export issues, and higher energy costs, some industries might decide to relocate their business outside Europe, with some facilities reducing production or closing their operations in Europe. Possible industry responses aimed at obtaining scarce wood resources would result in fierce market competition for wood to produce energy and for material use. This might be further exacerbated by high fossil-energy costs, and by shortage of wood supply, due to calamities and compliance with EU bans and trade regulations related to reduced wood imports, for instance from the 'Global South' and Russia.

An industry business-as-usual approach followed by diversification and adaptation

Due to regular felling and salvage logging, sufficient (and inexpensive) wood would be available on the market in the coming years. Maximising revenues on a business-as-usual basis would help industries to accumulate capital for the future investments needed to address climate change impacts, related to a profound transformation of the raw-materials base in Europe (an increase of mixed, deciduous and drought-adapted species). The wood industry will need to adapt to this change in raw materials by moving away from its current high dependency on softwoods. Moreover, wood supply might become more dispersed, and the industry may need to address this issue by means of new logistics, forest management practices, and institutional support for forest owners.

7.4.2 Forest managers perspective

Passive adaptive forest management ('Let nature do the job')

Under this scenario, it would be very difficult to maintain forest growth and forest species composition and structures as we know them today, due to disturbances related to climate change and global warming (e.g. drought, storms, fires, insects). Nevertheless, these disturbances could be passively taken advantage of by promoting natural regeneration processes involving low costs, thus helping in the transition towards new climate-adapted and resilient forests. In many parts of Central, East,

Exchange of stakeholder views in small group discussions at the TEAMING UP 4 FORESTS Think Tank 2023
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and South Europe, natural processes will cause more drought-resistant hardwoods (e.g. oaks, hornbeam) to dominate in the future if barriers to natural tree regeneration are managed.

Active adaptive forest management ('Assisted migration')

Implementation of active forest management to support the adaptation of species composition to climate change, and its related disturbances, would imply the replacement of the dominant spruce forests of today with plantations of drought- and climate change-adapted tree species mixtures, including introduced softwoods (e.g. eucalyptus species, Douglas fir, some pines) and hardwoods (e.g. oaks, hornbeam, beech). This could be augmented by investments in research focusing on forest adaptation, such as tree species responses to new climatic conditions. New knowledge would be needed, not only about tree species but also about the role of insects, ungulates and other game species, fungi, soils, etc.

7.4.3 Policy and society perspective

Non-native tree species policies

The existing EU and national regulations constraining the use of non-native and exotic tree species could be revisited under this scenario, and new supportive policies for genetically modified seeds, seedlings, provenances and varieties could be considered. In addition, conflicts between policies related to forestry, hunting and nature conservation might need to be addressed, giving priority to the regeneration of forests with drought-tolerant and resilient tree species.

Supportive policies for forest owners and industries

The adequate funding of knowledge transfer, advisory services, forestry machinery, and institutional organisation of small-scale forest owners would help to cope with the issues foreseen under this scenario. This could be combined with support for forest industries taking over forest management functions in privately owned but unmanaged forests.

Cross-sectoral policy coherence

Sectoral forest-specific and forest-related policies at the EU and national levels need to be better integrated and coordinated. A centralised EU forest adaptation policy and legal framework could help by providing a common and coordinated policy approach for forest planning and forest management. It could also provide political leverage in prioritising forest adaptation to climate change over other goals.


8

Chapter 8

Response Options

Authors: Michael Kleine, Nelson Grima, Carola Egger, Andreas Nikolaus Kleinschmit von Lengefeld

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8.1 Introduction

Drawing on all the information presented in the previous chapters, this chapter summarises possible response options for securing wood production and supply in and from European forests in the future while, as far as possible, maintaining key forest ecosystem services such as carbon sequestration and biodiversity conservation. As outlined, aspects of the ecological, social and economic systems that are expected to undergo significant changes over time have been analysed in this study, resulting in three different future forest scenarios (Chapter 6). As emphasised above, some developments within these scenarios may materialise in the real world in full or only in part, while others may not occur at all. Thus, future realities will most probably constitute a mixture of what these scenarios describe. Keeping these scenarios in mind, response options were developed by analysing the information distilled from the science-business-policy workshop held in June 2023. At this event, representatives of forest industries, private forest owners (PFOs) and public forest managers, forest policymakers, and social and natural scientists discussed the information contained in this study and provided their perspectives and insights.

In order to be effective, response options need to be tailored to the specific context where they will be applied. Considering this premise, the aim of this chapter is to present important general responses that allow anticipated future challenges within European forests and the wood-based sector to be adequately managed.

The chapter is organised along the lines of Chapter 7, where the input on consequences of the three defined future scenarios was classified according to the stakeholder groups attending the previously mentioned workshop, namely: forest industries; forest owners and forest managers; and political decision-makers and other stakeholders. All of these stakeholders are being, and will continue to be, challenged by changes not only in wood supply, but also in the complexity of the wider technical, economic, societal and political environment. In addition, some recommended responses for multiple actors that involve joint actions are summarised in the final section.

The takeaways and learnings from these recommended generic response options are intended to help the various actors to shape their thinking about how the future might look like, identify impacts on their own business and realm of work, and further develop response options tailored to their own specific local circumstances.

8.2 Options for response by wood-based industries

Global demand for wood-based products (both short-lived and long-lived) and multifunctional forest services is continuously growing. Wood and wood-material flows, both current and future, are largely determined by European and global markets' demands, in turn influenced by the relevant multifactorial policy environment. Technological advances and innovations in the European wood-based sector are key factors in the transition towards a circular bioeconomy. Emerging wood-based products are less dependent on specific wood species than traditional products, and many types of wood feedstock can be sourced. To this end, wood-based industries should **intensify and upscale technological development**, including the following:

- Continuing investing in and diversifying added-value fibre technologies, new wood and wood-based materials, as well as chemicals for every type of valorisation.
- Developing new co-production plans for higher efficiency in energy and materials uses.
- Investing and operating flexible transformation-process technologies for decreasing dependence on specific wood sources and qualities.
- Enhancing the creation of integrated value chains from sourcing to market.
- Benefiting (with bespoke solutions) from information and communication technologies tools to reduce time-to-market.
- Creating public-private partnerships for risk-sharing and for long-term investments

The sufficient availability, sustainable mobilisation and efficient logistics of (high- and low-quality) woody biomass will be crucial factors for the wood-based sector in the very near future and the coming decades. Sustainable mobilisation of woody biomass is affected by the demand for, and changing markets for, wood-based products at both a European and a global scale. Thus, a response option would be further **enhancing logistics strategies and efficiency** by means of the following:

- Gradually moving away from the current strong dependency on softwoods in core business operations. In the shorter term, diversification with

Changes in wood supply require responses by wood-based industries
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at least three tree species would be advisable given the need to cope with the consequences of profound climate change effects on forests.

- Setting new milestones to monitor and analyse the evolution of wood supply until 2030 and beyond, particularly to enhance quantification of available wood resources in the sub-regional context.
- Defining and measuring consumption per capita in Europe for adaptive planning and responses to disruptions and opportunities in the future.
- Including used and under-used wood in the supply mix to enlarge the material source. New supply chains should be developed for collecting and sorting used materials and waste.

Europe's reliance on global markets is acknowledged, while focusing on developing an added-value, knowledge-based circular and climate-neutral (i.e. net-zero) economy in Europe. Competition for raw materials and market share with other world regions such as Africa, Asia, North, and South America remains. This requires a new, **higher-quality standard of cooperation among European stakeholders and beyond** by means of the following:

- Enhancing the understanding of the complex wider framework and conditions under which sustainable mobilisation of wood (biomass) takes place, through multiactor approaches (e.g. cooperation among policymakers and forest owners).
- Harnessing the EU's political impetus vis-à-vis a net-zero (greener) economy to overcome regional competition between Europe and other global regions.

Harmonising the maturity level of the circular forest-based sector across European macro-regions through (pan-)European industry collaboration to promote green growth.

8.3 Options for response by forest owners and forest managers

As highlighted in the study, forests are highly sensitive to climate change. Trees' natural longevity, and the long timeframes involved in forest growth and production cycles in managed forests, do not allow for rapid adaptation to changes in the environment. Consequently, future management of forests for both wood production and other ecosystem services will need to be guided by adaptation principles and long-term strategies to achieve

Adaptive forest management practices will be key for forest managers and owners to supply wood
Photo © CasarsaGuru from iStock

future climate-fit forest ecosystems. Since the focus of this study is on wood supply, response options for forest management for wood production are summarised as follows:

- Given the expected climatic changes in terms of temperature increase and decrease in precipitation, coupled with increased occurrence and severity of natural disturbances (e.g. storms, fires, droughts, insects, pathogens), rapid application and scaling-up of **adaptive forest management practices** will be required. Whereas, for the Iberian Peninsula and the Mediterranean region, fire is now already the main disturbance factor, in Central and East Europe drought and bark beetle infestation in forests dominated by Norway spruce are key drivers of forest development. For Central Europe, adaptive forest management may entail the following:
  - Promoting mixed and structurally diverse forests wherever feasible, including natural regeneration and active, assisted migration of species that are more adapted to future climates (e.g. from Mediterranean climates in South Europe or dry continental climates of central-eastern regions), to build more resilient forests. As the future climate becomes more extreme, this could reduce losses, stabilise wood production and stocks, and outperform current management practices.
  - Reducing the proportion of climate-sensitive Norway spruce to minimise the amount of damaged wood caused by (among other factors) bark beetle infestation.
  - Where feasible, management of Norway spruce stands at low elevations may shift to planned rotation periods of 60–70 years as an intermediate strategy.
  - Wider introduction of productive non-native species, such as Douglas fir and/or others, to further enhance the effectiveness of climate adaptation strategies from a timber production-oriented forestry perspective. This may

also entail establishing high-yielding timber plantations of alternative species in line with best practices of biodiversity conservation at landscape scale.

- Seeking adequate financial support from governments and other investors for restoring forests after disturbances, and for protecting natural regeneration and new plantings, aiming to rapidly build climate-fit forest ecosystems.

- Further expanding scientific research in genetics and silviculture to enhance insights into the range of suitable species that are capable of tolerating future climatic conditions in specific environments within Europe.

- Expanding trial plantings, at operational scale, of more drought-resistant alternative tree species originating from other regions and exhibiting wood properties suitable for industry use.

- At global warming levels of approximately 2°C and with adaptive forest management widely applied, growing stocks and timber harvests could be stabilised, albeit at lower levels than those under current practices. Wood production is, at higher global warming levels of 3°C and beyond, likely to decrease in absolute terms. Both futures would require **closer cooperation between forest owners/managers and industry partners**, especially by means of:

  - Enhancing transparency of wood supply through monitoring and planning of wood harvesting and forest management.

  - Developing resilient wood supply chains to adapt to climate-driven disturbances (e.g. with wet-storage facilities).

  - Addressing fragmented forest ownership through management partnerships and consolidation.

  - Adapting to the disruptions and opportunities of more erratic wood harvesting through stronger collaboration between forest owners and industry partners in the short and longer term.

  - Expanding capacity building efforts and awareness campaigns to bridge the rural-urban divide in promoting active forest management for conservation, wood production and the provision of other ecosystem services.

8.4 Options for response by political decision-makers and other stakeholders

Political decision-makers will have to face the challenge of addressing the issues described in the previous chapters at global, EU, national and local levels. Even though these four different tiers are represented by different actors, decision-makers at each level should keep in mind the interconnections between levels and between the policies they draft.

Although some of the following response options can be considered cross-level, they can be generally classified as follows:

Global level

- **International forest governance:** Enhancing international and cross-sectoral cooperation and coordination, through organisations such as the UN Forum on Forests (UNFF), to address global challenges such as the effects of geopolitical developments, trade tensions, and sanctions on wood supply.

- **Forest research:** Promoting research and knowledge-sharing on related forest issues (e.g. ownership patterns, motivations of PFOs, effects of climate change, and biological responses from different forest species, including non-native species). A good understanding of forest-related issues is essential for informed policymaking.

- **Science-policy interface:** Strengthening the science-policy interface; this stands, so to speak, at the confluence of the two previous response options. It aims at providing policy makers with sound scientific knowledge for more informed decision-making. An example of this is the work of the Science-Policy Programme of the International Union of Forest Research Organizations (IUFRO).

EU level

- **Harmonisation of policies:** Facilitating better alignment and coherence between the various legally binding and non-legally binding EU policies, including those related to nature and biodiversity conservation, climate change mitigation and adaptation, and renewable energy. Reducing incoherence can help minimise trade-offs and uncertainties in forest management.

- **Promotion of sustainable forest management:** Emphasising the importance of sustainable forest management practices, including close-to-nature management and biodiversity-friendly afforestation and management practices. Encouraging the adoption of these practices through incentives and other support mechanisms.

- **Promotion of the circular bioeconomy:** Promoting societal engagement through awareness campaigns and educational programmes. This can enhance support for responsible consumption, emphasising the value of sustainable forest management in the broader context of environmental stewardship.

- **Market regulation:** Continuing to regulate and support the wood market to promote sustainable wood use while factoring in environmental, economic and social aspects. This includes subsidies and regulations related to construction, energy and the circular bioeconomy.

- **Forest resilience:** Developing strategies to enhance the resilience of European forests so they are better adapted to climate change effects and other external pressures. This may involve afforestation and reforestation with an emphasis on tree species diversity, the maintenance and enhancement of broadleaved hardwood species and the introduction of climate-fit species.

- **Regional supply chains:** Adapting to the trend towards regionalisation of (integrated) supply chains by ensuring that the EU has robust, diversified sourcing strategies and access to growing regional markets.

National level

- **Forest owner engagement:** Implementing initiatives to engage and incentivise PFOs to actively participate in sustainable forest management, especially in regions with non-traditional, urban, passive or absentee forest owners. Recognising that motivations may not always be profit-oriented, and considering personal and societal factors.

- **Demographic challenges:** Addressing demographic issues related to forest ownership by developing policies that cater to an ageing society and to potentially reduced demand for forest products. This could involve supporting alternative economic activities for forest owners.

- **Energy sector transition:** Acknowledging fundamental change in the energy sector, including the impact of rising electricity prices and shifts to renewable energy sources. Developing strategies to mitigate the potential economic impact on wood-based industries and wood supply. Avoiding frictions in the markets due to a lack of balance in public funding.

- **Geopolitical resilience:** Enhancing geopolitical resilience by diversifying sources of wood supply and reducing reliance on imports from regions affected by sanctions or trade tensions.

- **Economic incentives:** Introducing targeted financial incentives (e.g. subsidies, tax breaks) that encourage industries to invest in sustainable circular practices. By stimulating higher prices for sustainably sourced wood products and creating access to new markets, policies can incentivise industry transformation.

- **Research and innovation:** Investing in inter- and multidisciplinary research and innovation to develop integrated, sustainable wood supply strategies and technologies that can adapt to changing circumstances, including the regionalisation of supply chains and evolving market dynamics. Additionally, flexibility in regulations and harmonisation of administrative processes can enable quicker adoption of advanced and efficient technologies.

8.5 Options for response by multiple actors across the forest-related sector

As shown throughout this publication, the future of wood supply in Europe is of major concern to a wide range of actors and stakeholders. In the light of future uncertainties and changes outlined above, it is clear that society as a whole and the forest-based sector in particular are facing disruptive times. Given this background, and in addition to the response options listed above by groups of actors, the following potential responses are addressed to combinations of multiple actors across the forest-related sector:

- **Strengthening cooperation and collaboration on multiple levels** along the wood value chain, and involving stakeholders from outside this chain but also related to forests and wood as a resource. This may be implemented by means of the following:

- **Interdisciplinary cooperation:** Strengthening collaboration across disciplines could promote shared ambitions and common goals within the forest-based sector. Moreover, it could provide essential mechanisms for exchange of knowledge. For instance, active interchange between the scientific and business worlds can enable science-based decision support. In addition, multiactor dialogue and partnerships can drive robust and resilient business models and enable informed decision-making. An example of such a collaboration is the TEAMING UP 4 FORESTS partnership, which provides a science-business platform and offers a space for think tanks and discussions involving multiple stakeholders.

    - **Transnational cooperation:** Fostering cooperation at the pan-European and global level could be beneficial for all involved parties. For example, sharing of knowledge and best practice across countries could further adaptation strategies and technological advancements.

    - **Cross-sectoral cooperation:** Aligning among different lines of business in the wood-based industry, as well as with other industries and society in general, in order to enable strong and effective response measures. Forestry, wood, wood-based materials, renewable energy, new textiles, food additives, chemicals, pharmaceuticals, cosmetics and other emerging industries – supported by governments – would need to work together across countries in Europe and beyond towards high-value use of woody biomass.

- In addition to knowledge transfer through co-operation, **education and extension services** in general can play a key role in responding to and preparing for future developments. This can, for example, be crucial for engaging the youth and future generations.

- Apart from being utilised to inform the general public, **communication** within and beyond the forest-based sector could serve as an important tool for promoting effective response measures, thus helping with transition and adaptation strategies. This could, for instance, include designing and implementing persuasive information campaigns to emphasise the value of sustainable forest management for society. This could strengthen or improve the public's perception of the role of forest management.

Platforms such as TEAMING UP 4 FORESTS bring stakeholders together and foster collaboration
Photo © Jose Bolanos

Chapter 9

Conclusions

Authors: Nelson Grima, Maja Radosavljevic, Carola Egger

By merging multidisciplinary scientific knowledge with expert knowledge, the present study provides a synthesis of comprehensive transdisciplinary knowledge about key ecological, political, socioeconomic and technological factors influencing wood supply in Europe. This knowledge can contribute to raising awareness about the importance of anticipating, and strategically preparing for, the upcoming changes and challenges that the wood-based industry and its stakeholders (forest industry and business, forest owners and managers, policymakers and others) are already starting to experience, and will continue to experience in the future.

Securing wood supply while meeting climate and biodiversity goals, within a context of profound socioeconomic and environmental changes, will be a challenging and long-term process. This calls for immediate action including strategic planning, implementation, learning and adaptation. Through circular feedback loops, these efforts will shape future strategic planning, initiating a continuous cycle.

Strategic planning, the first step of the adaptation cycle, involves creating assumptions related to environmental, political, socioeconomic and technological factors that could impact the industry's processes in the future. Considering the long time spans involved in the wood-based industry, these assumptions may be hard to arrive at. Using the development of potential future scenarios as a tool facilitates the task by creating narratives that provide a context in which the different stakeholders can bring their own ideas to bear. These narratives allow for better integration of those ideas into the 'big picture', resulting in enhanced understanding of the potential new circumstances, alternative perspectives, and definition of possible actions to take.

The scenario development approach was used in this study. It allowed for in-depth interaction between the stakeholders involved, producing a set of ideas and recommendations to ensure the continuity of wood supply in Europe. Of these ideas and recommendations, the need for improved collaboration between science, industry and policy is highlighted in particular. This is largely seen as an investment, and it involves balancing the interests of a variety of stakeholders. In turn, it allows for continuous innovation, interchange and learning, which ensures flexibility and improved capacity to anticipate future changes and develop adequate actions to adapt (as necessary) to the new circumstances.

Focusing on the wood-based industry, the continuous rise in global demand for both wood-based products and multifunctional forest services significantly influences current and future wood flows in both European and global markets. Technological innovations play a pivotal role in transitioning towards a circular bioeconomy in Europe, enabling the creation of diverse wood-based products irrespective of specific wood species. Intensified investment – in the diversification of new fibre technologies, coproduction strategies, flexible transformation processes and integrated value chains – is essential. Additionally, fostering public-private partnerships and enhancing logistical efficiency are crucial actions to be taken. Diversification of tree species, monitoring wood supply evolution, integrating used wood resources, and understanding consumption patterns were further suggested strategies for sustainable wood mobilisation. Going forward, it will be vital to emphasise a knowledge-based circular economy while acknowledging competition for resources with other global regions, promoting cooperation, and harmonising the circular wood-based sector across European regions.

Among the ideas and recommendations that involve forest owners and managers more directly, it was highlighted that the acute sensitivity of forests to climate change emphasises the necessity for adaptive measures to manage forests, balancing the objectives of wood production and ecosystem services provision. A focus on wood supply will necessitate adapting species composition in favour of more heat- and drought-tolerant broadleaves, reducing the current dependence on climate-sensitive species such as Norway spruce. Financial support for restoring forests post-disturbance, close-to-nature management, expansion of scientific research in genetics, and trial plantings of drought-resistant species for industrial use would also be crucial. Stronger cooperation between forest owners and industry will be needed to maintain wood harvests, and this requires enhanced transparency, resilient supply chains, and the addressing of fragmented ownership. Capacity building and awareness campaigns to bridge rural-urban divides would be essential for promoting active forest management aimed at both conservation and wood production.

Political decision-makers face a multifaceted challenge encompassing global, EU, national and local levels, requiring a holistic approach that acknowledges the interconnectedness between these levels and their policies. At global level, there is a need for promoting extensive forest research, and strengthening the science-policy interface. Within the EU, the emphasis lies on harmonising policies, advocating for sustainable forest management, advancing the transition towards a circular bioeconomy, regulating markets, enhancing forest resilience, and adapting to regional supply chain trends. At the national level, strategies involve engaging private forest owners, addressing demographic shifts, ensuring geopolitical resilience, providing economic incentives for sustainable practices, and investing in research and innovation. All of these actions require multilevel collaboration and adaptive strategies to navigate the intricate challenges.

The ideas and approaches described in this publication can only be further developed and applied if all stakeholders involved are willing to collaborate, to consider different viewpoints, and to implement joint response options. The present study shows that such will exists. It also demonstrates that arrangements such as TEAMING UP 4 FORESTS – which has provided a platform for all stakeholders to meet and discuss, and for this study to be developed – are crucial in creating the right context from where solutions to ensure the future of wood supply, and the permanence of the wood industry in Europe, will emerge. The collaborative efforts outlined here are intended to serve as a beacon for industry innovation, adaptability and resilience in the face of evolving challenges.

Appendix I
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Appendix II
Glossary of terms and definitions used in the report

Adaptation (in relation to climate change impacts)	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2022).
Added value (in forest product industries)	The difference in economic value between the physical inputs and outputs of a production process. Within the forest products industry, the term “added value” has traditionally been used to describe what is more accurately called “secondary wood processing,” in which the output of primary wood processing operations (e.g. sawn lumber) is further processed into more refined wood materials or manufactured wood products (Sathre and Gustavsson, 2009).
Bioeconomy	Bioeconomy has been defined in various ways, and in a forest-based context can be understood to mean the utilisation of forests to create products and services that help economies to replace fossil-based raw materials, products and services. The forest-based bioeconomy links the whole forest value chain from the management and use of natural resources to the delivery of products and services (Wolfslehner et al., 2016).
Business-as-usual	Describes the continuation of standard activities and usual operations as they have been carried out until the current point in time. A business-as-usual scenario examines the consequences of continuing current trends in population, economy, technology and human behaviour (Alcamo et al., 2001).
Cascading (use / systems / aspects)	The efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system. From a technical perspective the cascading use of wood takes place when wood is processed into a product and this product is used at least once more either for material or energy purposes (BTG et al., 2016). This report mainly focuses on multistage cascading use of wood where a product is reused multiple times.
Climate change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the

	composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC, 2022).
Close-to-nature management	Close-to-nature forest management is a concept proposed in the EU Forest Strategy for 2030, which aims to improve the conservation values and climate resilience of multifunctional, managed forests in Europe (Larsen et al., 2022).
Economies of scale	Economies of scale refer to the notion that average cost falls as the firm expands (Carey, 2014).
Ecosystem	A dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (CBD, 1992).
Ecosystem (goods and) services	Ecological processes or functions having monetary or non-monetary value to individuals or society at large (i.e., the benefits people obtain from functioning ecosystems). These include i) provisioning services such as food, water, timber, and fibre; (ii) regulating services that affect climate, floods, disease, wastes, and water quality; (iii) cultural services that provide recreational, aesthetic, and spiritual benefits; and (iv) supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005).
Future of forests	In the context of this report, the term "future of forests" pertains to the upcoming decades, emphasising the anticipated changes, challenges, and opportunities in the evolving dynamics and sustainability of forest ecosystems.
Forest	Land spanning more than 0.5 ha with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use (FAO, 2020). Forests include both natural forests (sensu CPF, 2005) and planted forests (sensu FAO, 2020). It also includes areas temporarily unstocked, e.g., after disturbance, that are expected to revert back to forest.
Forest disturbance(s)	Damage caused by any factor (biotic or abiotic) that adversely affects the vigour and productivity of the forest and which is not a direct result of human activities (FAO, 2020).
Forests available for wood supply (FAWS)	Forest where any legal, economic or specific environmental restrictions do not have a significant impact on the supply of wood. Includes: areas where, although there are no such restrictions, harvesting is not taking place, for example, areas included in long-term utilisation plans or intentions (FAO, 2020).
Forest ecosystem (goods and) services	Ecosystem services derived from forests.

Forest management	The processes of planning and implementing practices for the stewardship and use of forests and other wooded land, aimed at achieving specific environmental, economic, social, and/or cultural objectives. Includes management at all scales such as normative, strategic, tactical, and operational level management (FAO, 2020).
Forest ownership	Generally, refers to the legal right to freely and exclusively use, control, transfer, or otherwise benefit from a forest. Ownership can be acquired through transfers such as sales, donations, and inheritance (FAO, 2020).
Forest policy	A set of orientations and principles of actions adopted by public authorities in harmony with national socioeconomic and environmental policies in a given country to guide future decisions in relation to the management, use and conservation of forest for the benefit of society (FAO, 2020).
Forest resource	Those resources found in forests and other wooded land, and as trees outside forests (FAO, 2020).
Forest sector	A sector of the economy and society that includes forest-based industries, forest managers and forest management organisations, forest researchers and research institutions, as well as other businesses, organisations and institutions working with or on the topic of forests and forestry.
Forest-based	For the purpose of this report, defined as “relying on resources from forests and trees”.
Forest-based industries	Industries relying on goods and services from forests for major parts of their production and business activities. The European Commission lists pulp and paper manufacturing and converting, woodworking, furniture and printing as the main sectors in this category.
Forest-based sector	See ‘Forest-based Industries’
Forest-based value chain	Describes a value chain in the forest-based sector. The activities involved in this type of value chain typically range from forest management and the direct obtainment of forest ecosystem services over transport to primary products including trade, export, and processing and subsequently to secondary products including further transport, consumption, and potentially recycling (sensu Wolfslehner et al., 2016).
Hardwood	Generally, refers to broadleaved / deciduous trees (e.g., oak, beech).
Intergovernmental Panel on Climate Change (IPCC)	Established in 1988 as a special body by the UN Environment Programme and the World Meteorological Organization to provide assessments to policymakers of the results of ongoing climate change research. The IPCC is responsible for providing the scientific and technical foundation for the United Nations Framework Convention on Climate Change (UNFCCC), primarily through the publication of periodic assessment reports (CBD, 2008).
Modelling	Development and use of models to translate scenarios into expected consequences for biodiversity and ecosystem services (IPBES, 2016).

Non-timber forest products	Any product or service other than timber that is produced in forests. They include fruits and nuts, vegetables, fish and game, medicinal plants, resins, essences and a range of barks and fibres such as bamboo, rattans, and a host of other palms and grasses (CIFOR, 2010).
Old-growth forests	The old-growth forests have been described by the adjective primeval, ancient, wilderness, virgin, pristine while in forester's terminology they are called as over-matured, decadent, and senescent, old growth. The old-growth forests may be defined as a climax forest that has never been disturbed by man. The old-growth forests can be classified as per the age and disturbance criteria (EEA, 2023).
Other wooded land	Land not classified as "Forest", spanning more than 0.5 ha; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use (FAO, 2020).
Private forest ownership / private forest owners (PFOs)	Forest owned by individuals, families, communities, private co-operatives, corporations and other business entities, religious and private educational institutions, pension or investment funds, non-governmental organisations (NGOs), nature conservation associations and other private institutions (FAO, 2020). These private owners are referred to as PFOs.
Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover. The word representative signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term pathway emphasises that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (Moss et al., 2010).
Set aside	Forest management strategy in Europe, where countries generally have a greater area of even-aged planted forests approaching biological maturity than old-growth forest (Barbati et al., 2014).
Shared socioeconomic pathways (SSPs)	Currently, the idea of shared socioeconomic pathways (SSPs) is developed as a basis for new emissions and socioeconomic scenarios. An SSP is one of a collection of pathways that describe alternative futures of socioeconomic development in the absence of climate policy intervention. The combination of SSP-based socioeconomic scenarios and *Representative Concentration Pathway* (RCP)-based climate projections should provide a useful integrative frame for climate impact and policy analysis (IPCC, 2023).
Softwood	Generally, refers to coniferous trees that have needle- or scale-like leaves (e.g., pine, spruce).
Scenarios	Stories / narratives of a range of potential futures. Scenarios are one of the most widely known techniques used in strategic foresight. They are written in compelling, accessible language, often as if the events have come to pass. Scenarios support strategic foresight's focus on the many possible futures by developing alternate possible futures.

Strategic foresight	Also called futures – a transdisciplinary field of inquiry that uses a variety of methods to explore possible, plausible, and preferable futures. The goal is to develop foresight – insight into how and why the future could be different than today – to improve policy, planning, and decision-making.
Sustainable forest management (SFM)	A dynamic and evolving concept. Aims to maintain and enhance the economic, social, and environmental values of all types of forests, for the benefit of present and future generations. The seven thematic elements of sustainable forest management are: (a) extent of forest resources; (b) forest biological diversity; (c) forest health and vitality; (d) productive functions of forest resources; (e) protective functions of forest resources; (f) socioeconomic functions of forests; and (g) legal, policy, and institutional framework. The thematic elements are drawn from the criteria identified by existing criteria and indicators processes, as a reference framework for sustainable forest management (UN, 2007).
Value chain	The value chain describes the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use (Kaplinsky and Morris, 2001).
Wood supply	Availability and procurement potential of wood and fibre for the *wood-based industry*. Refers to a subcategory of the provision of forest ecosystem goods and services.
Wood-based	For the purpose of this report, defined as "relying on wood as resource from forests and trees".
Wood-based industry	The wood-based industry describes a sub-category of the forest-based industry. For the purpose of this report, the term is used to refer specifically to businesses relying on wood and fibre for their operations. We focus on pulp and paper industries due to the fact that within our capacities most insights and knowledge could be gathered with regards to this industry branch.

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This report has been prepared in the framework of TEAMING UP 4 FORESTS, a platform initiated by IUFRO and Mondi.

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