ALTERFOR

Deliverable 4.4 – Making the forest fit for the future:

Road Map for Implementing Alternative Forest Management Models in Europe

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Abbreviations used

CSA – Case Study Area
C – Carbon
CF – Characterisation Factors
ES – Ecosystem Services
FMM – Forest Management Model
aFMM – alternative Forest Management Model
G4M – Global Forest Model
DSS – Decision Support System
EU – European Union
IPCC – International Panel for Climate Change
MKB – Modified Kronoberg System
PM, MFM, SAFM – Alternative Forest Managements n the EU until 2100
RAFL – Recreation and Aesthetic value of the Forest Landscape
WP – Work Package

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Summary

European forests are expected to provide broad range of Ecosystem Services. The forest capacity is, however threatened by the uncertainties of climate change, the complex dynamics of evolving global markets and the pressures for increased use of bioenergy.

Innovative approaches to forest management are decisive in strengthening the capacity of forests to meet these challenges better in the future. Forest Management Models (FMMs) describe different management practices existing in the European forests that can be optimized with the aim of delivering a specific bundle of Ecosystem Services.

This Road Map provides information on how the FMMs approach can be applied to particular forest areas. It shows options for designing FMMs on different levels, from stand over the landscape to the European, offering a checklist for tailoring successful strategies of forest management.

The Road Map is based on the experiences from 10 Case Study Areas (CSAs) in 9 European countries, from North-, South-, West-, East- and Central Europe. Existing methods of managing the forest in CSAs are categorized and described under current FMMs. In addition, the stakeholders were involved in discussing possibilities of changing the outcome of a current basket of Ecosystem Services provided by current FMMs so that also alternative ways of managing the forest were formulated – alternative FMMs (aFMMs), and included into the long term perspective with the help of modelling. Finally, the Road Map directly addresses the new means of linking sound scientific results with multiple and conflicting interests of stakeholders in order to facilitate the implementation of alternative FMMs in the future.

Objective of the deliverable

The objective of the road map is to provide a role model for how research and practice can collaborate in designing and implementing improved FMM alternatives in the future. The overview over the scientific results of ALTERFOR in systematics of FMMs and models on local, regional and landscape level should provide the reader insights into the scientific achievements of ALTERFOR. In addition, the report on multi-stakeholder integration should trigger ideas how to proceed in a specific case. Finally, the focus on the relevance of ALTERFOR results and methods for practical issues should show how practitioners and researchers find a common ground in making use of those results and methods for optimizing sustainable forestry in the future.

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1. Introduction: making the forest fit for the future

European forests are expected to provide a broad range of Ecosystem Services. The forest capacity is, however threatened by the uncertainties of climate change, the complex dynamics of evolving global markets and the pressures for increased use of bioenergy.

Forest management is the key tool in strengthening forests and their capacity to meet these challenges better in the future. Forest Management Models (FMMs) describe different management practices existing in the European forests and can be optimized with the aim of delivering a specific bundle of Ecosystem Services.

This Road Map will provide you with information on how to apply the FMMs approach to the forest area of your specific interest. It shows you options for designing FMMs on different levels, from the local over the landscape to the European one, and offers a checklist for tailoring successful forest management projects based on that.

The Road Map should be useful for both scientists as well as practitioners. Whereas scientists will realise how to link scientific, sound FMMs with their implementation in the field, the field foresters will learn about the support they can get for their work in the forest by specific FMMs. Stake holders will learn how to specify multiple forest functions into respective Ecosystem Services of the forest through FFMs and how to choose effective policy tools to support them.

The Road Map is based on the experiences from 10 Case Study Areas (CSAs) in 9 European countries, from North-, South-, West-, East- and Central Europe. Present methods of managing the forest in CSAs were categorized and described under Forest Management Models (FMMs). Stakeholders were involved into discussing possibilities of changing the outcome of a contemporary basket of Ecosystem Services provided by current FMMs so that also alternative ways of managing the forest were formulated (aFMMs) and included into the long-term (50 to 100 years) perspective by modelling. The Road map offers the main findings about current and alternative FMMs from the 10 CSAs and their scientific basis is presented in following chapters:

Chapter 2: The basis – 10 Case Study Areas of the ALTERFOR project and the key issues
Chapter 3: Why the concept of Forest Management Models (FMMs)?
Chapter 4: The long-term (50-100-year) perspective – results from Case Study Areas
Chapter 5: Insights for policy making
Chapter 6: Scientific basis of FMMs cases, obstacles, limits and opportunities
Chapter 7: Global models
Chapter 8: Facilitating implementation of FMMs by stake holder analysis and involvement
Chapter 9: Tailoring a project for improving the forest by FMMs
Chapter 10: Suitable research institutions in different case countries

Summing up, the Road map will provide the reader with science-based insights how the approach of forest management models (FFMs) can be used to make the forest fit for multiple challenges by increasing demands for Ecosystem Services from the forest in Europe.

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2. The basis: 10 Case Study Areas of the ALTERFOR project and the key issues

All case studies were conducted by the large-scale research and innovation project ALTERFOR funded by the European Union (EU) programme Horizon 2020[1]. Its aim is to facilitate the implementation of innovative FMMs[2] better suited to meeting the challenges of the 21st century. This is pursued by:

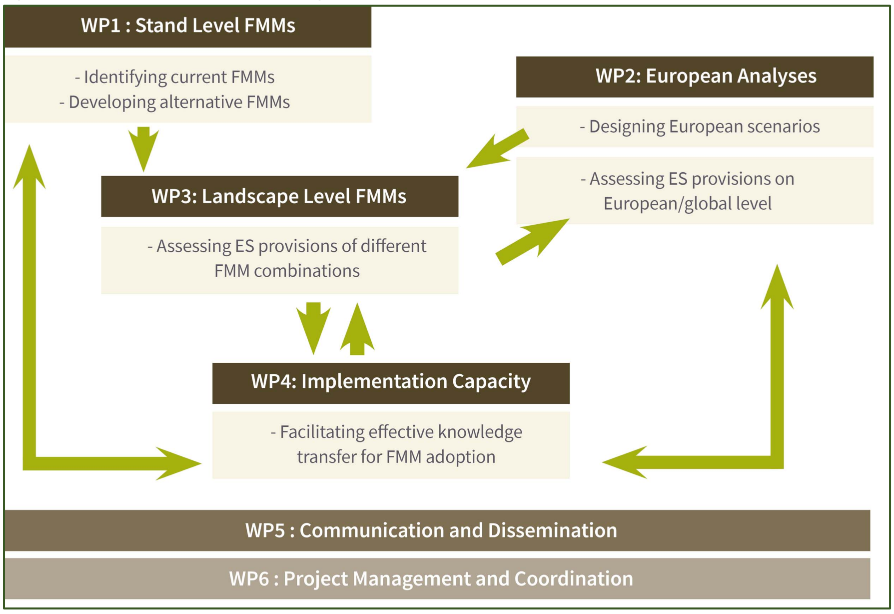
(1) Identifying and developing FMMs robust in their capacity to deliver Ecosystem Services and overcome projected socio-ecological risks and uncertainties.

(2) Assessing the impact of different FMM combinations in terms of resultant Ecosystem Services baskets on the European and landscape level.

(3) Facilitating the implementation of desired FMMs and improving cross-national knowledge transfer regarding their benefits, costs, management, and utilization.

To accomplish project tasks, ALTERFOR has been organised in six Work Packages (WPs). The interrelations of these WPs are presented in Figure 1.

Figure 1. ALTERFOR Work Packages



The project involves a consortium of 19 organisations from nine countries chosen to represent the diversity of Europe's socio-economic conditions and prevailing forest management paradigms (Figure

[1] ALTEFOR is 4.5 year's project ending in September 2020, and with the total budget of 4,000,000 Euro.
[2] In ALTEFOR, Forest Management Models (FMMs) refer to forest management approaches at (i) stand level, ranging from a specific forest operation (e.g. a forest logging technique) to a silvicultural schedule extending over decades (e.g. thinning regimes) and (ii) landscape level such as forestland zoning or sustained yield requirements.

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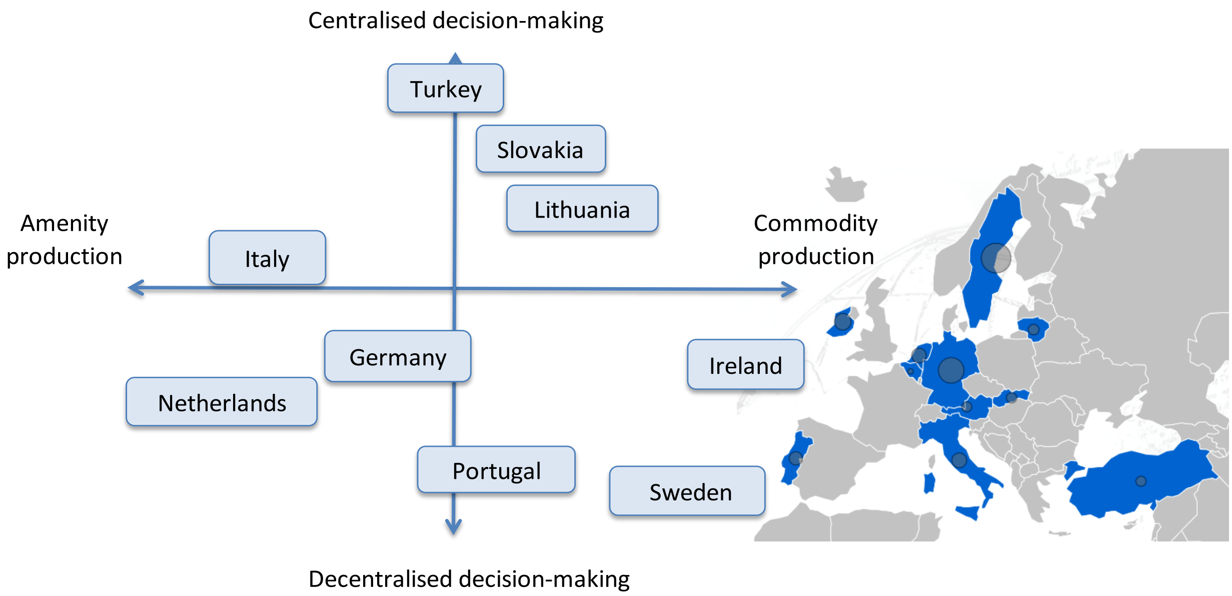
2). For example, in Sweden there is a need to innovate and implement coordination among private forest owners in order to balance the traditional profit-oriented timber production, with the increasing need for climate change adaptation and growing societal demands for amenities. In contrast, within Turkey there is a need to deal with the centralised forest management routines of state forestry administration, to find more adaptive and cost-efficient solutions producing such forest amenities as water and soil conservation. The Netherlands represent one of the heavily populated European countries where recreational amenities supersede the economic values of forest. The Dutch forest legislation is liberal and the key challenge is to identify and implement such approaches to managing private forests that could be more congruent with the changing societal priorities. Timber production is still an important priority in Ireland, however, the extensive conifer monocultures on peatlands point at historical mistakes in the choice of tree species. Now, there is a sharp need for novel forest management models that would better commensurate timber and biodiversity values.

Figure 2. Current goal-orientation and degree of centralisation in forestry of ALTERFOR case countries



More information:

- Project deliverables: https://alterfor-project.eu/wp4.html
- Deliverable 4.1 – Report on actors driving forest management in selected European countries
- Deliverable 4.2 – Report on supporting local and national networks for forest management model alternatives
- Deliverable D4.3 – Report on supporting international networks for forest management model alternatives

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3. Why the concept of Forest Management Models (FMMs)?

The concept of Forest Management Models (FMMs) has met increasing interest in the forest literature in the last decades (Dunker et al. 2012; Hengeveld et al. 2012) when discussing and describing the use and management of forests. By tradition however, foresters have long discussed and studied silviculture systems (Mathews 1989). What is then a silviculture system and where is the difference to a stand-level FMM?

Mathews (1986, p. 3) defines **silviculture system** as "*The process by which the crops constituting a forest are tended, removed, and replaced by new crops resulting in the production of stand of distinctive form*". One possibility to identify and categorize silvicultural systems is by the origin of trees – from seed or vegetative (suckers or coppice). Another possibility is the use of trees and related harvesting options – if trees are harvested mainly when they reach a mature size or if small dimensions are harvested. It is the terms high forest and low forest that are then often used. Another option is to use criteria of removing trees. Are all trees removed in one final harvest, a clear-cut, or harvested in a selective way? With different terminologies and the possibilities to combine operations, it is easy to imagine how the facilities for confusion grow.

A key concept in the ALTERFOR project is thus to work with the **Forest Management Models** (FMMs). The **concept of FMMs is more detailed than the concept of silvicultural systems**. It is also described or defined by the main activities or tools used in the different countries. For discussion on distinction between silviculture systems and stand-level FMMs see Dunker et al. (2012).

The use and outcome of FMMs are dependent on complex factors, like environment, the growth conditions and tree species, on economic and social situation as well as legislation. A system used in one part of the Europe can, in practice, differ when implemented elsewhere and give other outcomes. The FMMs therefore include wide range of activities, applied in different phases of the stand development, for example soil preparation and thinning.

3.1 Data collection

During **autumn 2016,** the local case coordinators described the most important and common **stand-level FMMs** used in their Case Study Areas (CSAs). This was done with the help of a detailed questionnaire. Information was also collected with respect to **regeneration methods**, **tending operations**, **thinning program**, **rotation period** and **tree species**. The current FMMs were classified depending on the **silviculture system**.

Information about **Ecosystem Services provided by the FMMs** has been reported, too. The Ecosystem Services explicitly considered in the ALTERFOR project were **wood volume production, biodiversity, carbon sequestration, cultural services, regulatory services and water related services**. Ecosystem Services in most CSAs were **ranked** for each current stand-level FMM. Simple and efficient approach for providing an approximate ranking of the current ES was devised by ALTERFOR´s expert group on Ecosystem Services, in cooperation with the CSA partners. This ranking enabled comparisons of FMMs within particular CSA but not between different CSAs, meaning that high ranking of an FMM in one CSA does not necessarily indicate equally high ranking on other CSAs.

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3.2 FMMs in different countries

There is a **large variation in forestry of the 9 countries** participating in ALTERFOR. There is also a difference in the number of FMMs reported in the CSAs, from 12 in Lithuania to one in Italy (**Error! Reference source not found.**).

The most common silviculture systems among the FMMs (Table 2) are the clear-felling (13) and non-uniform shelter system (12). Selective systems are not used very often – four FMMs are described as selective models. Coppice is used in 4 models, together with clear-felling system of an admixture in two other models and also one model for conversion from coppice to uniform shelterwood system.

Clear-felling systems and uniform shelter systems both result in even-aged forest, at least for most of the rotation period. These two systems are used in 22 FMMs and so make the contribution of 39% from the total area (23% + 16%, Table 2).

Table 1. Number of reported FMMs for each partner

Country	No of FMMs	Total area of CSA (ha)
Germany, Bavaria	3	120 000
Germany, Brandenburg	3	60 000
Ireland	9	77 528
Italy	1	315
Lithuania	12	253 970
The Netherlands[1]	9	4 154 300
Portugal	4	14 850
Slovakia	10	151 768
Sweden	6	840 000
Turkey	8	81 808

Encompasses the entire country; CSA – Case Study Area; FMMs – Forest Management Models.

Selective systems and non-uniform shelterwood system both result in uneven aged forest. These two systems are used in 16 FMMs, and in 4 systems, combinations with selective or non-uniform shelter-wood systems were used. Totally 20 FMMs with uneven-aged forest are estimated to cover 34% (13%+12%+9%) of the area (Table 2).

Table 2. FMMs classified in silviculture systems

Silviculture system	**Number of FMMs**	**Estimated cover %, total all CSA[1]**
clearfelling	13	23
uniform shelter	9	16
selective	4	13
non-uniform shelter	12	12
more than one selective[2]	4	9
coppice	4	7
combination with coppice	2	3
transformation from coppice	1	0.3

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no intervention	6	5
not defined (or combination of two or more systems[3])	4	1.5

FMMs classified in silviculture systems, number of FMMs and estimated proportion of area where they are used. The sum is not 100 % as all alternative FMMs are not described.

[1] Not weighted by area of CSA (Case Study Area) instead assuming each CSA have equal size

[2] Selective, two or more systems combined at least one selective system resulting in uneven-aged forests

[3] Not selective systems

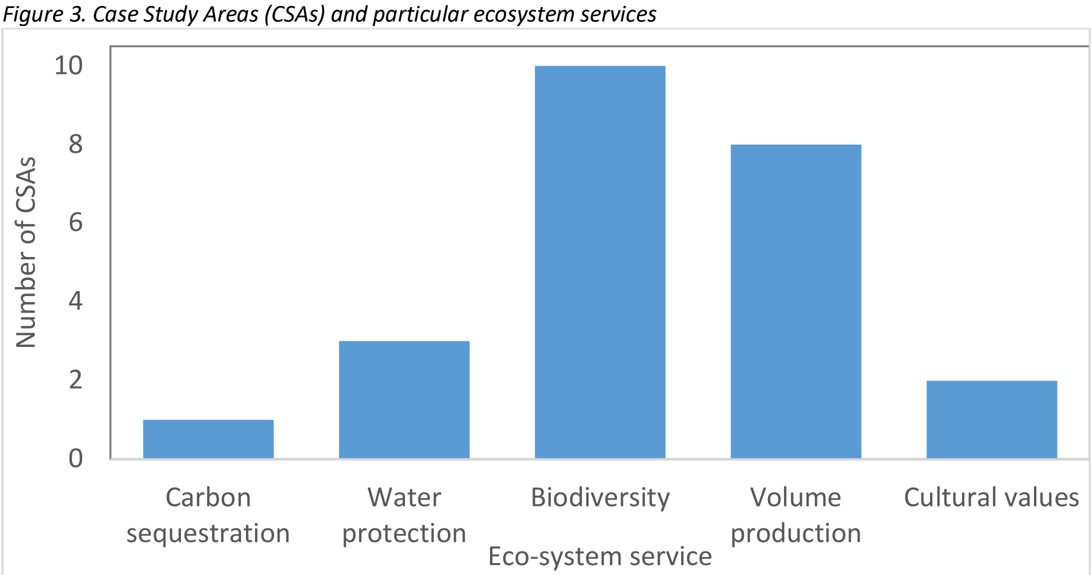
3.3 Work with alternative FMMs

After describing the situation with current FFMs, the next step in ALTERFOR was to work with alternative FMMs (aFMMs). Most current FMMs deliver timber but a main target with ALTERFOR is **scrutinizing the possibilities to increase provision of a bundle of Ecosystem Services.**

Many scientists working in ALTERFOR where heavily involved in the process of **formulating the aFMMs** in the CSAs. In some countries, scientists were those suggesting one or more aFMMs while in some CSAs the first steps towards aFMMs where taken by **stakeholders**. An alternative FMM was intended to be realistic in terms of climate, tree species and more, offering the possibility to do long time forecasts of growth and yield. The implementation of most aFMMs requires moderate levels of new research or technical development, meaning that most aFMMs can be implemented without violating current laws or certification rules, however the situation varies a lot between countries.

The two main Ecosystem Services that had been mentioned in CSAs as motivating the development of alternative FMMs were **biodiversity and volume production** (Figure 3). In all ten CSAs biodiversity was mentioned as the main reason for the choice of an aFMM and in the eight CSAs the volume production was highlighted (Figure 3).

Figure 3. Case Study Areas (CSAs) and particular ecosystem services



Number of Case Study Areas (CSAs) that mentioned a particular ecosystem service as a reason to develop alternative Forest Management Models (aFMM). There were ten CSAs in total.

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Protecting and managing **regulating Ecosystem Services** (especially water) and increasing the usability of forests for recreational activities are also reported as drivers in some CSAs (Figure 3). However, **carbon sequestration was rarely mentioned as the main motivation**.

Information from CSAs also shows clear trend in **opinions that the amount of broadleaved species will increase in Europe if the aFMMs are implemented**. The aim of many aFMMs is to increase the proportion of broadleaves in mixed species stands with conifers whereas aFMMs for creating monocultures of broadleaves are rare.

The main reason for choosing the clear-cutting systems with for example Douglas fir, as suggested in Sweden, is the potentially higher wood production. Wood production is also the goal for some aFMMs in Germany, Portugal and the Netherlands. In Slovakia, the reason for frequent thinning is to provide small landowners with a continuous income, while in Lithuania adaptive rotation length is proposed for increasing productivity and income.

In some of the aFMMs combination of wood production and biodiversity are mentioned as the main reason. In Ireland for example, the low-stocked lodgepole pine aiming for fiber will allow for regeneration of native shrubs and trees for biodiversity at the same time.

More information:

- Deliverables and Milestones at: https://alterfor-project.eu/wp1.html
- Deliverable 1.1 – FMM descriptions
- Deliverable 1.2 – Alternative Forest Management Models for ten Case Study Areas in Europe

4. The long-term (50-100-year) perspective: results from Case Study Areas

The following chapter offers insights into selected modelling results. The scenarios for the provision of different Ecosystem Services in the long-term (50-100-year) perspective are presented and described, showing diversity across project´s CSAs.

4.1 GERMANY: making a difference in the long run – optimal carbon sequestration by managed forest

In the long run, continuous carbon sequestration is only possible if the forest is managed. This effect is caused by saving CO2 emissions due to the substitution of other products by wood products.

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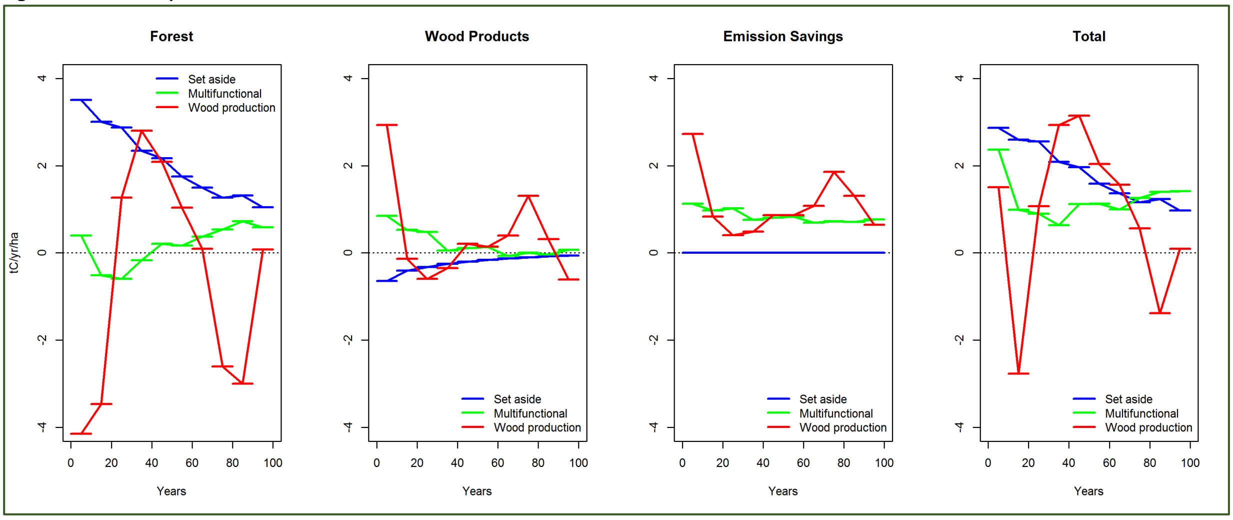
Figure 4. Germany: carbon balances



Carbon balances depending on forest management scenario for 100 years of the forest itself (“Forest”), of the related wood product stocks (“Products”), emission savings due to wood product use (“Emission savings”), and the total balance (“Total” = all three components). Positive carbon balances indicate a net carbon uptake, negative balances indicate a net carbon release.

The alternative forest management scenarios of the **53 000 ha forest area of Augsburg Western Woods** compare the annual carbon balances by (i) set asides (blue), (ii) multifunctional (green) and (iii) maximum wood production (red) on 100% of the area (Figure 4). Positive and negative carbon balances indicate an increase and a decrease of the stored carbon amount respectively. The strong oscillations in scenario (iii) are due to the uneven age class distribution that is not regulated in this scenario.

In each scenario, the total carbon balance is the sum of the balances in the forest plus in products made of harvested wood plus saved emissions due to using wood instead of other raw materials.

The results for this specific, **highly productive forest area with Norway spruce** as the dominating species proof that set asides (blue, Figure 4) show a high carbon uptake in the forest by the growing and not harvesting trees. As all wood remain in the forest and wood products have a limited lifetime, the uptake in the existing wood product stocks is even negative in the beginning and – most importantly – emission savings are zero. As the stands in the set aside scenario approach their maximum biomass, their carbon uptake is strongly declining during the simulation period.

The multifunctional scenario (green) and maximum wood production (red, Fig. 4), in contrast, do not accumulate substantially more carbon in the forest on the long run (balances oscillating around zero). Similar trends are evident for their wood product balances; the initially positive balances indicate a temporary increase of the stored carbon amount that, however, levels off after a few decades (product carbon balances oscillate around zero). In contrast to the set aside however, both scenarios provide ***permanent* carbon emission savings in the order of magnitude of 1 t carbon per year and hectare forest.** This results from the permanent sustainable provision of wood as a raw material. The use of this wood instead of other raw materials (steel, concrete, etc.) avoids carbon emissions in the above-mentioned order of magnitude.

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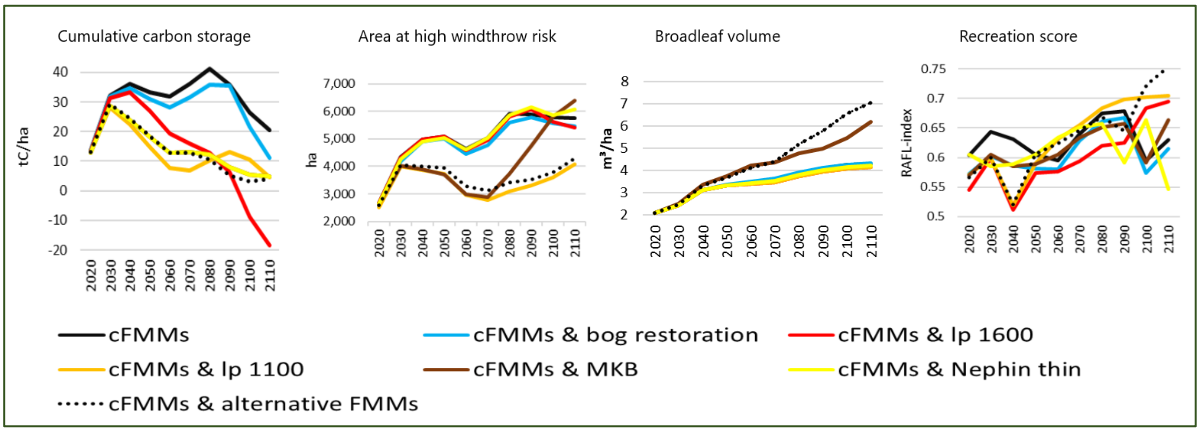
While the total carbon balance is strongly oscillating in the production scenario and quite stable in the multifunctional scenario, they both have virtually the same *average* carbon balance in the long run (i.e. over the whole simulation time span). After 100 years, the total carbon balance of the set aside scenario decreased to about the same level, but with a further decreasing trend. Due to the emission savings, the two management scenarios will have a persisting carbon sequestration effect on the long run.

4.2 IRELAND: Making the most of blanket bog forests – improving economy, biodiversity and recreation, while reducing windthrow risk

Utilising a combination of alternative forest management to transform existing blanket bog forests can lead to improving multiple forest Ecosystem Services. It is unlikely that these forests can provide high timber volumes and high net profits in the long perspective, but existing timber can be removed followed by cheaper reforestation option. Re-evaluating their expected Ecosystem Service provisions and permanently re-designating their management objectives can lead to long-term improvements for biodiversity, and recreation, while reducing the risk of wind throw.

Figure 5. Cumulative carbon storage, area at high windthrow risk, broadleaf volume and recreation store



Cumulative carbon storage per hectare, area at high windthrow risk, broadleaf volume per hectare, and recreation score for the seven model scenarios, using the existing Forest Management Models (FMMs), a combination existing FMMs and an individual alternative FMMs (five model scenarios), and using existing and all alternative FMMs. Of the 10,000 ha forest, the final established area with each individual alternative FMM was 422 ha, 5219 ha, 5224 ha, 172 ha, and 3397 ha for bog restoration, lp 1600, lp 1100, MKB, and Nephin Thin. The total established area of each alternative FMM in the model scenario using existing and all alternative FMMs was 4 ha, 3538 ha, 1238 ha, 179 ha, and 376 ha for bog restoration, lp 1600, lp 1100, MKB, and Nephin Thin. The alternative FMMs are explained below in text.

The aFMM bog restoration referred to restoring bog to their natural habitat and was aimed at Natura 2000 sites in our model. Lp 1600 refers to low-stocked planting of lodgepole pine at 1600 stems/ha to produce biomass over 50-60 year rotations. Lp 1100 refers to low-stocked planting of lodgepole pine at 1100 stems/ha, which will be retained indefinitely and is supposed to support biodiversity. MKB, or Modified Kronoberg System, is a planted mixture of Sitka spruce with a birch as a nurse species – this management is suitable for sites with shallow blanket peat and enables sawlog

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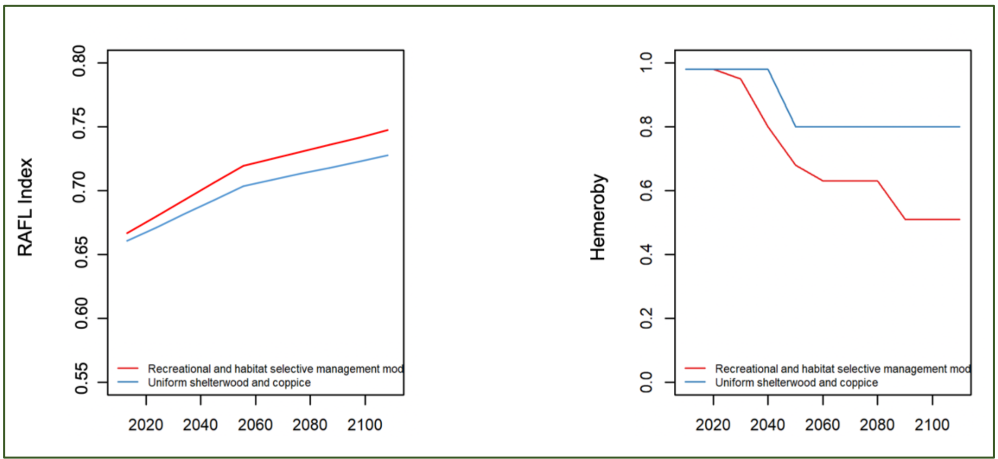
production without the need for fertiliser. Nephin thin is a management action where existing lodgepole pine stands are heavily thinned to around 450-550 stems/ha, to extract existing timber, followed by retention to provide a semi-open forest habitat.

The model objective was to maximise NPV from mill-gate sales over 100 years, using a 5% discount rate. The model scenarios resulted in NPVs of €16.7 M when only using existing FMMs, and €19.4 M when using existing and all alternative FMMs – all other scenarios were somewhere in between. Utilising a combination of alternative FMMs lead to more optimal land management, higher NPV and, overall, better provision of several Ecosystem Services, compared to only utilising one alternative FMM at a time. These alternative FMMs were developed for Ireland's western peatland forest, and although carbon storage declines the results show that improvements can be achieved in provision of biodiversity, recreation windthrow risk, and NPV by changing the forest management and using lower-stocked lodgepole pine management systems lp 1600 and lp 1100 (Figure 5).

4.3 ITALY: Recreation next-door in the middle of nature

Active forest management can couple cultural Ecosystem Services and recreation opportunities with forest naturalness and nature conservation, ensuring multiple benefits for society.

Figure 6. Recreational and Aesthetic value of Forested Landscape and hemeroby index



Recreational and Aesthetic value of the Forested Landscape RAFL Index (0 = low value, 1 = high value) and hemeroby index (0 = natural and non-disturbed landscapes and habitats; 1= far from natural landscapes and habitats) depending on alternative forest management models for 100 years. Hemeroby index measures the magnitude of the man-induced deviation from the potential natural vegetation occurring in a certain area.

The alternative forest management scenarios for the **ca. 300 ha forest areas of the Lowland Forest Association (North-Eastern Italy)** compare the trends in the Recreational and Aesthetic value of the Forested Landscape (RAFL) index and hemeroby index by (i) Recreational and habitat selective management model (red) and (ii) Uniform shelterwood and coppice management model (blue) (Fig. 6). The RAFL index consists of several concepts and dimensions, including (among others) stewardship, naturalness, complexity and openness, that – combined together – influence the recreational and

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aesthetic value of a forest landscape. Hemeroby measures the magnitude of the man-induced deviation from the potential natural vegetation occurring in a certain area.

The two alternative management models show divergent paths for both indexes considered, resulting in an increasing gap over time. The Recreational and habitat selective management model is inspired by the idea of bringing forests closer to natural conditions by supporting species mix and improving the proportion of broadleaves. Fluctuations in the hemeroby index are due to harvesting operations like thinning, to support natural regeneration of native species while maintaining large trees, but also other management solutions locally favouring evolution towards "native" holm-oak forests by removing senescent pine trees. Active management will lead to less dense stands and favorable conditions for recreational activities by locals and tourists (hiking, bicycling, sport and leisure activities), while at the same time reducing wildfire risks. All together, these features make the RAFL curve steeper, turning forests more suitable for the delivery of cultural services while conserving/enhancing environmental values.

In the Uniform shelterwood and coppice management model shelterwood cutting is applied in order to reduce canopy cover, open gaps and, ultimately, facilitate natural regeneration. The coastal forests will be gradually brought towards holm-oak forests by removing pine trees and support holm-oak regeneration. Part of the pine stands will be left for recreational purposes and shelter for locals and tourists. Overall this will result in an increase in the hemeroby index after 20-30 years, however limited by the fact that holm oak forests will be managed as coppices with standards, with a rotation period of 35 years. Coppicing will ensure some firewood production but, on the other hand, forests will be less attractive from a recreational and aesthetical point of view.

After 100 years, both management models show an increasing trend for the RAFL index and a stable hemeroby index. The Recreational and habitat selective management model delivers the best combination of recreational and conservation opportunities.

4.4 LITHUANIA: Forest management model matters more than the climate change and our efforts to mitigate it

The impact of forest management model (FMM) on delivery of Ecosystem Services seems to be larger than the one of climate change. Thus, acknowledging global human efforts to mitigate the climate change, forest management at local level plays a decisive role in reducing negative impacts and benefiting from the positive climate change impacts on forests and forestry.

Figure 7. Impact of alternative FMMs on delivery of forest ES in the period 2020 – 2060

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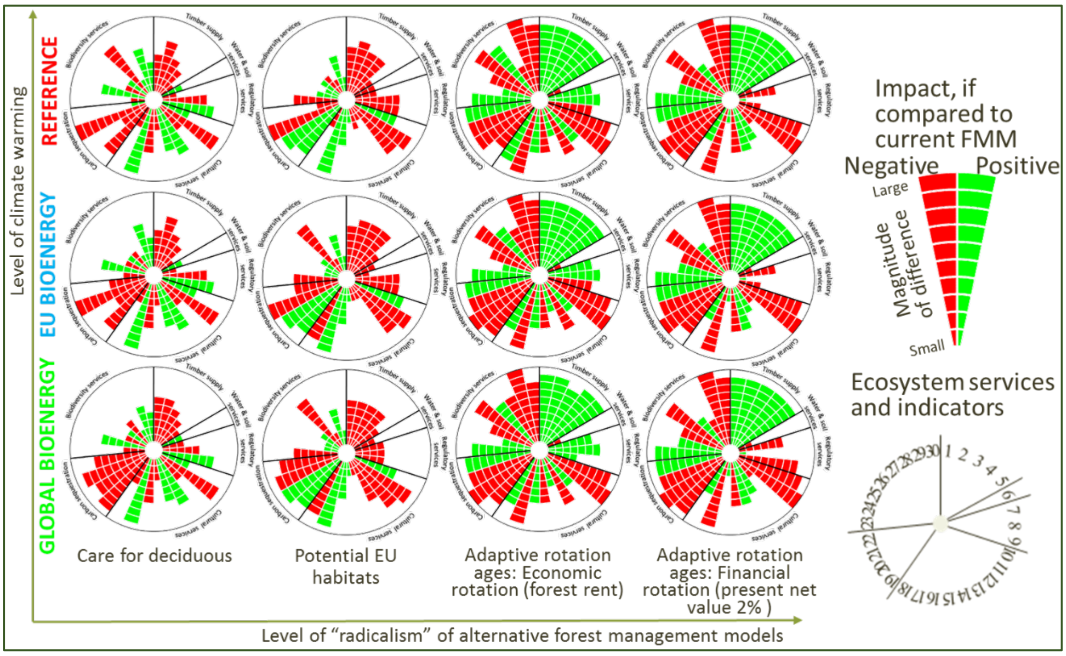

Impact of alternative FMMs on delivery of forest Ecosystem Services in the period 2020-2060, depending on climate change mitigation scenario. Trends of ES if current FMM is continued are compared with the outputs of alternative FMMs under the same climate change scenario. ES and indicators are: timber supply (1 – total volume of harvested timber, 2 – volume of sawlogs, 3 – volume of pulpwood, 4 -volume of cutting residues, 5 – profit of forestry activities); 6 – water and soil protection grade; regulatory services (probability of mortality due to: 7 – wind, 8 – diseases, 9 – competition); cultural services (10 – amount of cutting residues, 11 – area of clearcuts, 12 – naturalness, 13 – natural deadwood, 14 – species diversity, 15 – age diversity, 16 – visual penetration, 17 – understorey, 18 – share of broadleaved); carbon sequestration (19 – balance, 20 – biomass, 21 – harvested wood products, 22 – substitution); biodiversity (23 – increment/harvest ratio, 24 – species diversity, 25 – age diversity, 26 – age; 27 – share of broadleaved, 28 – natural deadwood, 29 – proportion of trees >50 cm, 30 mean diameter)

Development of forest resources and forestry was simulated for the case study area (~**90000 ha** of forest land) in **western part of Lithuania** under three climate change mitigation scenarios, assuming different human efforts to mitigate the global climate warming and, thus, differing in forest yield, timber demand and price trends. Delivery of Ecosystem Services was estimated for the period until 2060, considering that current forest management practices are continued. Then, the provision Ecosystem Services was modelled to test **four alternative FMMs**, differing by the level of changes in forestry regimes. The alternative FMMs were: (i) care for deciduous, which largely reminded the current forest management with increased focus on prioritizing deciduous tree species during reforestation and thinnings, (ii) no management on potential habitats of European importance (~9% of the area); and two FMMs based on adaptive minimum allowable rotation ages, namely, (iii) economic rotation or maximum forest rent, i.e. aiming for average annual net income and (iv) financial rotation or maximum present net value using 2% interest rate. The last two models were going much beyond current forestry framework, associating final harvesting age with site productivity and economic reasoning, usually (but not always) resulting in shorter rotations. Then, we calculated relative differences in values (in %) of each Ecosystem Services indicator, comparing outcomes from current FMMs versus all four alternative FMMs, by climate change mitigation scenarios. All absolute difference values were classified into 10 quantiles. Figure 7 summarizes the differences – here, one piece of the

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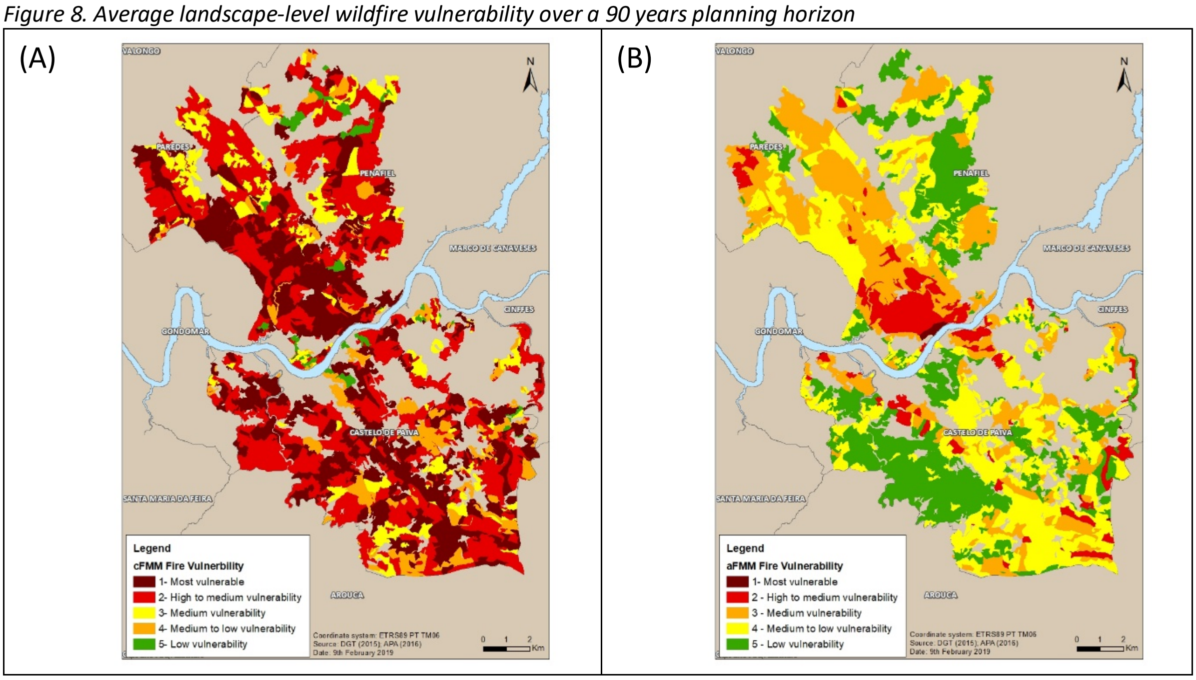
wedge represents 1 quantile and the colours are associated with the direction of change of respective Ecosystem Services indicator under specific alternative FMM vs current FMM. It seems that the changes are notably larger along the x-axis, which represents the level of "radicalism" of alternative FMM compared with current FMM, than the changes along y-axis, which indicates the changes due to different climate change-mitigation-scenarios, i.e. due to different forest yield levels, timber demand and prices. It should be noted that different indicators within the same Ecosystem Services type could experience radically different impacts of applied alternative FMMs, e.g. neither notably increased timber harvesting under adaptive rotation ages did not automatically reduce some cultural or biodiversity related Ecosystem Services, nor the additional no-management areas did always improve the biodiversity potential.

4.5 PORTUGAL: Changing forest management can decrease vulnerability to wildfires

Introducing alternative forest management models that involve more frequently fuel treatments, may contribute to decreased vulnerability to wildfires in Vale do Sousa.

Figure 8. Average landscape-level wildfire vulnerability over a 90 years planning horizon



Average landscape-level wildfire vulnerability over a 90 years planning horizon: (A) only with current FMMs, (B) Introducing alternative FMMs and increased frequency of fuel treatments.

In this example, we assess the **vulnerability to wildfires of the Vale do Sousa case study area (14.837 ha) under two management planning scenarios**. The reader is referred to Ferreira et al. (2015) for a detailed description of the wildfire resistance indicator used to classify that vulnerability. In the first management scenario we consider the use of current stand-level forest management models (FMMs) over the 90-years planning horizon while in the second we consider also the use of alternative stand-level FMMs. Moreover, in the former we assume a business as usual scenario with no coordination of fuel treatment schedules across the landscape. Contrarily, in the second scenario,

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we consider a landscape-level joint management approach that contributes to increase the coordination and frequency of fuel treatments.

Results show that in the case of the first scenario, high vulnerability areas (red and dark red) are predominant across the landscape (Figure 8, A). In contrast, the introduction of alternative FMMs – including species such as pedunculate oak (Quercus robur) and cork oak (Quercus suber) – and the increase of the frequency of fuel treatments extend the areas where vulnerability to wildfires is medium or low (yellow and green) (Figure 8, B). The introduction of alternative FMMs and the increased frequency of fuel treatments were a consequence of a participatory planning process where the stakeholders negotiated forest management objectives for the whole area (Borges et al. 2017, Marques et al. 2020). This landscape-level management planning approach contributed to the coordination of fuel treatments across the study area and was influential for the decrease of the vulnerability to wildfires and to the design of a more resilient forest mosaic.

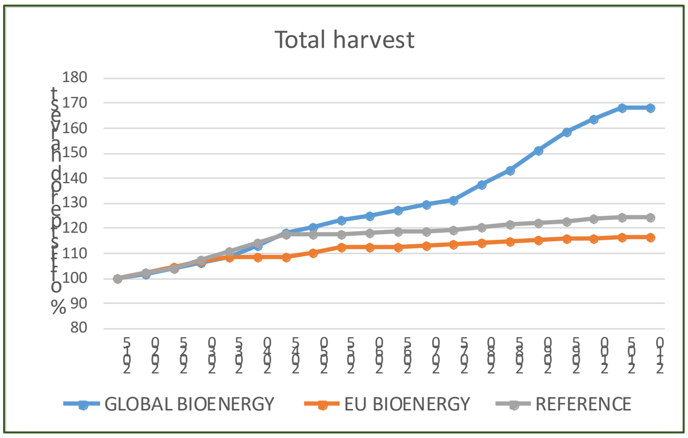
The full development of the landscape-level management planning approach was supported by decision modules (Marto et al. 2019). The latter encapsulate models and methods to project the provision of Ecosystem Services over the 90-years planning horizon, to provide information about the trade-offs between Ecosystem Services and help stakeholders negotiate the plan that best meets their objectives, namely the reduction of the vulnerability of the landscape to wildfires.

In practice, the landscape-level management planning approach helped address two of the most important forestry challenges in the study area: wildfire risk and property fragmentation.

4.6 SWEDEN: Climate change mitigation scenarios driving alternative forest management pathways in the Swedish CSA

Meeting the big increase in demand in GLOBAL BIOENERGY required further intensification of forest management practices in the Swedish CSA. The more modest increase in EU BIOENERGY and REFERENCE enabled diversification to promote biodiversity conservation and reduce climate change related risks.

Figure 9. Projected harvests



Projected harvests (expressed as percentage of first period harvest) of roundwood (sawlogs and pulpwood from thinnings and final fellings) in the projections with aFMMs in the three different climate change mitigation scenarios.

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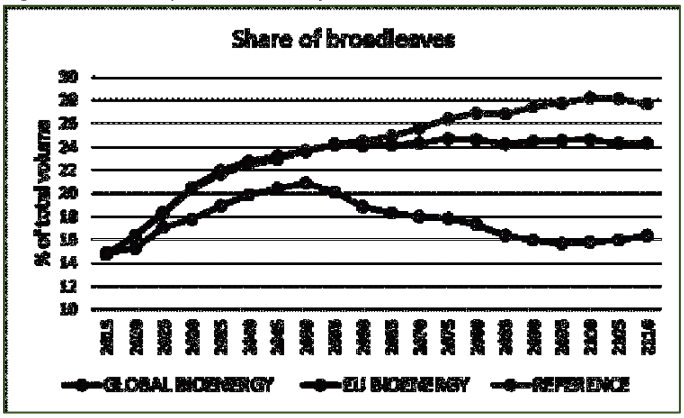
Figure 10. Development shares of broadleaves



Development for the shares (% of total volume) of broadleaves in the projections with aFMMs in the three different climate change mitigation scenarios.

Meeting the projected demands in the different climate change-mitigation-scenarios was a priority when defining alternative forest management pathways in the Swedish CSA. The tree different climate change-mitigation-scenarios (GLOBAL BIOENERGY, EU BIOENERGY and REFERENCE) provided very different trajectories with respect to future drivers of forest management. GLOBAL BIOENERGY implied limited warming (1.5 °C higher by 2100 than the pre-industrial level) and a massive increase in wood demand (see Forsell and Korosuo, 2016). EU BIOENERGY and REFERENCE implied substantial warming (2.5 °C and 3.7 °C degrees respectively higher by 2100 than the pre-industrial level) and more modest increases in demand.

All three alternative forest management pathways could meet the projected demand in the three different climate change mitigation scenarios (Figure 9). Achieving this in GLOBAL BIONERGY required substantial intensification of forest management from the current level, including shorter rotations, fertilization (in all pine stands > 16 m), Hybrid larch (21 % of the reforested area during the projection period) and reforestation with productive clones of Norway spruce (38 %). At the same time, the demand in EU BIOENERGY and REFERENCE could quite easily be meet with current practices, and there was room to soften the intensive practices in the CSA. The alternative forest management pathways projected in these two scenarios therefore implied diversification of forest management, including continuous cover forestry (on 13 % of the forestland), mixed forests (EU 6,5%/ REF 13 % of the reforested area) and reforestation with Oak (EU 3 %/ REF 6 %). The diversification in EU BIOENERGY and REFERENCE implied positive developments for the share of broadleaves (Figure 9b) and other biodiversity related indicators. Trying to meet the big increase in demand in GLOBAL BIOENERGY would result in negative effects on other Ecosystem Services, such as biodiversity. Hence, climate change mitigation might amplify existing conflicts between the provisioning of different Ecosystem Services, stressing the need for suitable forest policies and forms of governance to handle this “balancing act”.

It is important to stress that the projected **effects of climate change on growth are highly uncertain**. The ease of meeting the demand in EU BIOENERGY and REFERENCE is partly due to the very positive impacts of climate change on growth currently implemented in the Swedish decision support system Heureka. Recent research indicate that these effects are too optimistic (Subramanian et al., 2019) and in addition negative effects of various abiotic and biotic disturbances on growth are poorly accounted for.

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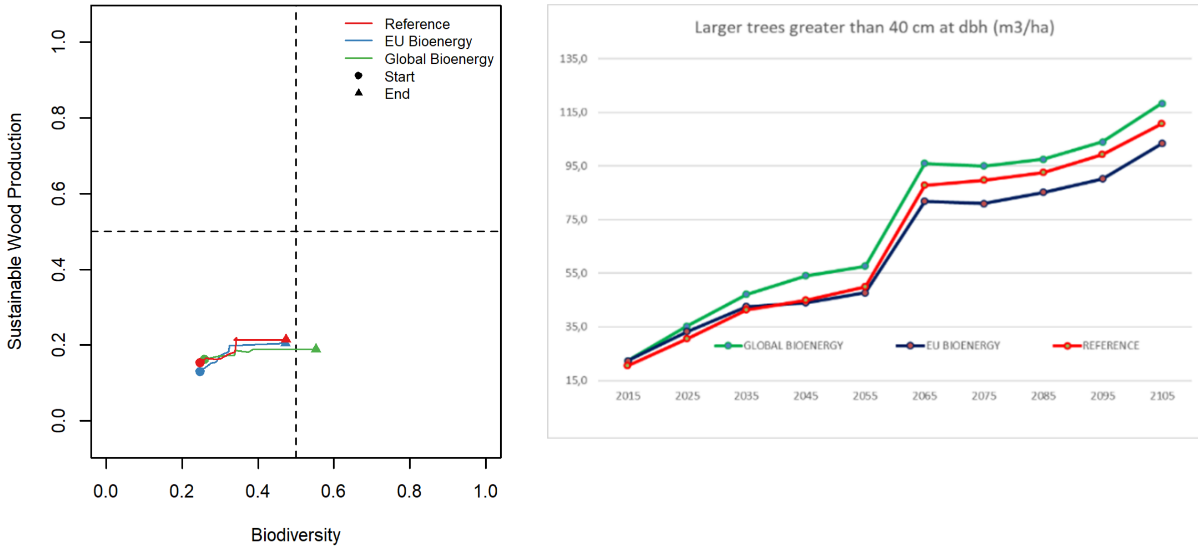
4.7 TURKEY: Effects of continuous forest management on biological diversity

Positive changes are observed in terms of biodiversity outputs when continuous cover forest management model is included in different scenarios. Although, some parameters remain constant such as species composition or harvest production, the shift from thinner to thicker developmental stages and the accumulation in dead wood pools result in increase in biodiversity.

Figure 11. Gölcuk Case Study Area



In the **Gölcük case study, multifunctional silvicultural concept, which includes "Continuous Cover Forestry"** as an alternative forest management scenario, was applied considering global frame scenarios in a **40,978 ha** forested area, where nearly 7% of forest land is degraded. Especially the **beech dominated** stands with various aged/sized trees created as part of either mismanagement or social conflicts necessitates continuous cover forestry to provide primarily ecological and socio-cultural forest values to the society.

We observe a slight increase in sustainable wood production (from very low to still low levels) along with a considerable increase in biodiversity with no considerable frame scenario differentiation. The increment increases from 4 m^3/ha to nearly 5 m^3/ha with small fluctuations and the harvest volume much more increases from 12 to m^3/ha to 26-28 m^3/ha to meet the demands of frame scenarios such as the amount of wood assortments or price levels. On the other hand, the standing volume is nearly doubled from 160 m^3/ha to over 300 m^3/ha during a 100-year planning horizon.

The driving factor in the increase of biodiversity is the abundance of big trees (>40 cm) that increased from nearly 20 m^3/ha to 120 m^3/ha at the end of the planning horizon (Fig. 10). Increasing age of stands and the increase in standing volume have positive effects in the abundance of big trees and the amount of deadwood. Coarse dead wood from nearly 0 m^3/ha to 1 m^3/ha. This result is also a reflection of forest regulation in force since 2006, dictating conversion of forest structure from coppice to high forest besides continuous cover forestry. In continuous cover forestry, regeneration is allowed in small areas. Thus, risk is minimized, standing volume maintained (no clear cut or in small areas) and all Ecosystem Services are assumed to be served at best. The practices of continuous cover

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forestry coincide with the ecological requests of beech trees. According to silvicultural guidelines no:296, either the natural tree species or the species mix should be kept or followed after the regeneration or during the thinning operations. Therefore, the share of tree species remained the same between the scenarios. Consequently, the contribution of the species diversity was limited.

More information:

- Lodin, I.; Eriksson, L.O.; Forsell, N.; Korosuo, A. Combining Climate Change Mitigation Scenarios with Current Forest Owner Behavior: A Scenario Study from a Region in Southern Sweden. Forests 2020, 11, 346.
- ALTERFOR Deliverables: https://alterfor-project.eu/wp3.html
- Deliverable 3.3 – Proceedings from open workshop
- Deliverable 3.4 – Synthesis report: New FMMs in a landscape perspective: Innovation needs and gains in ES provisioning

5. Insights for policy making

The insights of ALTERFOR extend well beyond the CSAs to policy making at national and transnational levels. Here, we provide an overview of what we see as some of these key insights.

Steering potential with regard to tree species diversity: The fact that across the CSAs the use of aFMMs could either increase or decrease the values of biodiversity indicators as well as the volume of broadleaves in some CSAs, indicated considerable steering potential with regard to tree species diversity that was replicated across the breadth of countries included in the ALTERFOR assessment. This is an important finding simply because it highlights the potential extent of the flexibility European countries may have in terms of altering the tree species diversity, and thus potential adaptive capacity of their production forests.

How to integrate and interpret outcomes for cross country comparisons? The "Fuzzy Logic" approach is a highly promising standardized means of integrating and interpreting outcomes for cross-country comparison in research and policy formulation. This approach enabled us to develop consistent landscape-level indicators for biodiversity, sustainable wood production and carbon sequestration. The former two are based on a fuzzy logic rule system, while the latter directly transforms wood volume information into carbon stocks and balances, including forest-bound stocks, stocks in harvested wood products, and substitution effects. We see this approach as being directly relevant to the larger context of European forest policy and the challenges of simulating and contrasting forest biodiversity and the Ecosystem Services that societies depend upon. Furthermore, the fuzzy evaluation system is easily amenable to integrating local practitioners' views into assessments, a vital component especially in those regions with large numbers of small-scale forest owners.

Global Bioenergy scenario: a vital insight was gained from the lack of a consistent increase in harvest volume in all CSAs in the Global Bioenergy scenario. This scenario included substantial global and local increases in the demand and price for timber as a result of efforts to reduce the severity of the climate change effects. The assumption behind this scenario was that wood production is an important means of contributing to climate mitigation, and that timber will be an essential part of the

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bioeconomy if climate change is going to be mitigated. This inconsistency across CSA in changes to harvest volume could indicate that for the stakeholders in some CSAs, the production of other Ecosystem Services was more important than satisfying the demand for timber, with the expectation that the extra timber will come from other forests, possibly in other countries. What this may indicate, is that a ‘Not In My Back Yard’ (NIMBY) approach could override the need for global solidarity and the sharing of the burdens of climate change mitigation. This requires further investigation. A key caveat here is that many of the ALTERFOR case study areas exercise conflict potentials between ES delivery. This might imply that increasing harvest volumes in these regions was more difficult than in each country’s overall forest estate, thus exaggerating a possible future timber supply problem. In either regard, the relationships between timber supply and demand, and climate change mitigation, are vital issues to consider in the context of forest carbon sequestration. If a large forest area is managed sustainably in the long-run, its net C sequestration in forest-bound and wood product stocks will be zero. In this case, the only remaining sequestration effect is C emission savings due to utilising wood instead of fossil raw materials. Obviously, this is the effect the Global Bioenergy (and also the EU Bioenergy) scenario is counting on. Notwithstanding the potential limitations as discussed in the obstacles section below, the results for all CSA / aFMM combinations indicate that sustainable wood production is maintained, with the primary exceptions occurring in those cases where harvest is deliberately limited, as was the case in “Nature Conservation” aFMMs in the German CSAs. However, given the issues discussed above, and the need of forest owners and stakeholders to satisfy the societal demand for a wide range of Ecosystem Services, it appears that it may become very difficult to cover the future European and global timber demand, especially if something akin to the Global Bioenergy scenario becomes reality.

Pathways for maximising carbon sequestration capacity: an important point arises in this regard with direct relevance to which pathways nations can take to maximise the carbon sequestration capacity of their forests. CSAs with aFMMs characterized by high sustainable harvest rates, generally exhibited low forest C sequestration rates. In contrast, low impact systems with a low level of harvest compared to the actual increment generally have higher sequestration rates. However, it is important to consider that close to nature or no timber harvest strategies could lead to a decline in stand production and forest C sequestration over time. More specifically (e.g., the German aFMM Production forest), the forest carbon sink can be low due to higher timber demands, but a larger increase in emission savings in products resulted in a larger overall sink. This finding is consistent with other stand and regional level analysis (Lundmark et al., 2016; Oliver et al., 2014). However, in other cases where there is a large demand for pulp (e.g., Kronoberg CSA in Sweden), the decline in the forest sink due to large increases in the level of harvest may not be offset by HWP storage, simply because of the small expected C half-life of pulp and paper products. German examples provide important additional insights. The Nature conservation aFMM in the Augsburg Western forests (Germany) represented an interesting case because it offered no HWP or product substitution potential and yet it was observed that the forest C sequestration decreased over time as stands approached the maximum biomass per unit area. Results from the German CSA may suggest that, although old growth forests are considered to act as small C sinks (Luyssaert et al., 2008), low impact systems may not always offer the largest overall C sequestration potential in the long term. In addition, diversion of C from selective harvests can potentially maintain high growth rates, and hence forest C sequestration, whilst also contributing to wood product substitution. An important point here is that

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whereas sequestration in forests and through wood utilisation are often considered as opposite pathways, both wood utilisation and Forest C paths contribute to total C storage, and overall sequestration may be maximised if the combined sequestration in the forest and in wood products is optimised.

More generally, *for the considered time span of 100 years most of the simulations show that overall C sequestration may be maximised if sequestration in the forest is prioritized*, though any such conclusions must be tempered by uncertainties stemming from the lack of inclusion of disturbance impacts (e.g. fire, pest, windthrow). As a consequence, low impact aFMMs with a low level of harvest compared to the increment have the highest C-sequestration rates. From this perspective, the problem of how to fight climate change best with forest management comes down to a strategical decision between two extremes: i) maximize sustainable wood production (especially for products with long life spans) in order to have maximum 'eternal' C-emission savings, or ii) try to achieve maximum C sequestration rates in forest-bound stocks with very low harvest amounts. As forest C stocks cannot be sinks forever, the idea behind this strategy would be to gain time until advanced technological solutions for reducing C emissions become ready for use. This suggests that systematic scenario runs should be used to find optima between both extremes as an important task for the near future.

Deciding between low and high impact forest management, as mentioned above, must also be seen from a risk perspective (which was the focus of the regulatory services' assessment), because stands with high densities and large standing volume/biomass, are usually more risk prone – especially in terms of windthrow and snow damage – than intensively managed thinned stands managed at lower densities. In the latter case, individual trees can develop more stability in the long-run, while in dense stands stability is only maintained as long as the whole collective remains intact. In addition, build-up of deadwood C stocks may present a higher fire risk (Vilén and Fernandes, 2011) and large disturbances were not factored into the DSS. Thus, the degree of desired risk avoidance is an important consideration with respect to the intensity of forest management adopted. A promising general insight from the aFMM results is, however, that the use of aFMMs usually decreased, or at least did not increase, the long-term risks. This suggests that forest management alternatives chosen to provide a more desirable combination of Ecosystem Services seem to be generally coupled to neutral or positive outcomes with respect to risk reduction, a key insight considering climate change projections for the coming century.

Role of simulation and optimisation models: The degree of detail provided by ALTERFOR in the silvicultural scenarios and associated Ecosystem Services provisioning modelled, and the inclusion of large-scale market and climate change scenarios as well as stakeholder preferences, is to our knowledge unprecedented in its application to such a large collection of forest DSSs and diverse forested landscapes. From the experiences gained so far, we learned that a most important field for DSS, model and scenario development in the near future would be the integration of extreme climate-related events (e.g., storms, extreme droughts, flooding). However, this requires that climate scenarios contain information about the frequency and intensity of such events. In addition, this also requires that forest simulation models and DSSs are able to simulate the impact of such stochastic events on trees and stands, stand structures and forest landscapes at adequate levels of resolution. While the outcomes of ALTERFOR clearly indicate the potential to increase the provision of all considered Ecosystem Services individually, the obtainable synergies and trade-offs often vary from region to region due to their specific forest conditions, history, and social and regulatory requirements.

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Whereas these results could suggest the use of caution with respect to overly uniform EU forest policies, they can more confidently be used to emphasize the crucial role of simulation and optimisation models in the exploration of forest dynamics and Ecosystem Services provisioning at the landscape level under complex changing global and local conditions.

More information:

- ALTERFOR deliverables and milestones: https://alterfor-project.eu/deliverables-and-milestones.html
- Lundholm et al. (2020): Evaluating the impact of future global climate change and bioeconomy scenarios on ecosystem services using a strategic forest management decision support system. https://www.frontiersin.org/articles/10.3389/fevo.2020.00200/abstract

6. Scientific basis of FMMs cases, obstacles, limits and opportunities

Here, we provide a brief reiteration of the methods before discussing obstacles, limits and opportunities.

The work in ALTERFOR was based on CSAs in nine European countries. **Each country used its own Decision Support System (DSS) / forest simulation model.** This had the advantage that projections were done with the best possible applicability for the specific CSA conditions. There was however a key but unavoidable disadvantage with this approach. The inherent diversity in applied methods meant that the overarching global frame scenarios prepared by the International Institute for Applied Systems Analysis - IIASA (ALTERFOR WP2 Leaders, 2016), containing the climate and timber demand scenarios, could not be incorporated in the same way and to the same extent in all case studies. In order to partly overcome methodological differences resulting from the application of different projection tools and different ways of incorporating the global frame scenarios, ALTERFOR defined a standard set of output variables as a common requirement to be provided by all case studies (Nordström et al., 2019). A core basis of ALTERFOR results was the evaluation of alternative forest management model implications for biodiversity and a range of Ecosystem Services. Note that these results were not uniformly defined across the CSAs. Rather, each CSA defined their own aFMM or several aFMMs based on the concepts that turned out to be serious alternatives for important local stakeholders (see ALTERFOR Deliverable D3.4). Note that if an aFMM was applied in more than one global frame scenario, it had to be adapted in order to take into account the different market and climate developments coming with the frame scenarios (see WP1 for FMM details).

6.1 Differences in the DSSs applied

Fundamental differences existed in the DSSs used among the CSAs. This is readily discerned from the risk assessment component of ALTERFOR, which we use here as a case in point. Whereas Ireland, Lithuania, and Portugal used empirically based models; Germany, Slovakia, Turkey, and Netherlands used an approach that was strongly reliant on expert input and translated into a numerical risk index (classification systems in which evaluations were more or less dependent on subjective inferences).

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In contrast, Italy and Sweden used qualitative evaluations. None of the countries but Portugal has criteria that depend on spatial relationships and on the landscape mosaic that results from the spatial distribution of stand-level FMMs; probabilities or indices are calculated on landscape quantities (in most cases computed as the sum over stands). Portugal used vulnerability probabilistic models that also depend on stand spatial configuration and context. This pattern whereby each CSA embraced DSS approaches that varied extensively in their capabilities was replicated across the biodiversity and ES assessed.

6.2 Differences in scenarios considered and the trade-offs between regional relevance and cross-country comparison

There was a general but incomplete overlap among the CSAs in the scenarios assessed within a particular task (e.g. ALTERFOR Deliverable 3.4), with three CSAs adding "Business as usual" to the three core global frame scenarios (i.e., Reference (high climate forcing), EU bioenergy (medium climate forcing), Global bioenergy (lower climate forcing), and one CSA lacking the Global Bioenergy scenario. Climate forcing refers to the amount of energy the Earth receives from the sun, and the amount of energy radiated back into space, with changes to this radiative equilibrium now being caused by altered greenhouse gases in our atmosphere. In addition, and more importantly, the CSAs differed in whether the models were applied comprehensively, or selectively, to the alternative FMMs considered for assessment. For example, in some circumstances four of the countries (Germany, Lithuania, Portugal, Italy) comprehensively contrasted each of the scenarios assessed, with each aFMM to be adopted. By so doing, the respective implications of the aFMMs versus the scenarios could be evaluated. In contrast, three countries (Slovakia, Sweden, Turkey) coupled the production "intensity" of the aFMMs adopted with the scenarios assessed. This approach was generally motivated by the underlying premise that the scenarios within which lower levels of GHG emission were achieved required more intensive forest-dependent climate change mitigation (this approach was thus consistent with the scenario assumptions stated). Notably, in those CSAs in which this linkage occurred, it is of direct relevance to the interpretation of outcomes, as there is an inherent linkage between the extent of anthropogenic climate change and the forest management approaches applied. In other words, a country may retain natural regenerating uneven-aged forestry in the Reference scenario, whereas it adopts intensive even-aged introduced planted stands in the Global Bioenergy scenario. This means that improved climate mitigation is associated with highly distinct forest management approaches and intensity, and vice versa, with corresponding implications for how modelling outcomes can be interpreted with respect to what is actually driving outcomes.

In addition to these complexities, some countries provided additional adjustments to forest management scenarios that were contrasted across the global frame scenarios. For example, Portugal addressed the implications of different fuel treatments for preventing forest fires; Slovakia assessed the implications of increasing the protected forest area, and the restitution of ownership rights; whereas Lithuania considered two different approaches to optimizing rotation lengths for financial returns. Outcomes were likewise influenced by regional differences in starting conditions and the, sometimes recent, implementation of specific policies likely to have strong implications for resultant outcomes and the breadth of alternative management directions available. For example, in Portugal recent policy changes restricts the use of Eucalyptus, in Turkey forest regulation is promoting the use of high forest over coppice, whereas in Ireland there are multiple policy initiatives to increase the use of broadleaves and reduce impacts on water quality.

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The timber services' assessment provides an additional case in point of these differences between CSAs. Whereas almost all the CSAs provided the full set of relevant variables in their simulation result reports (see MS12 document), often only a subset of these was included within the CSAs' specific reports about timber. In some cases, additional variables were included in the CSA reports, such as basal area, with these results excluded from cross-country comparisons as few countries were consistent in the additional details added. In some CSA reports, the outcomes of individual aFMM implications were reported separately, but in other reports the aFMMs were introduced as a complete set, resulting in only one result per global frame scenario. In some reports, comparisons were made with the current FMM results. Unfortunately, for several CSAs these comparisons did not make sense, as the models and data used had been updated and improved for the aFMM analysis, hence confounding the distinction between methodological differences and the impact of alternative FMMs. Nevertheless, for some CSAs the current FMM analysis was repeated with the updated models and data, and therefore comparison between current FMMs and alternative FMMs results was possible.

These differences in approach, scenario considerations, aFMM adoption and associated interactions, understandably translated into CSA specific outcomes requiring innovative means of comparison (see Fuzzy logic below).

6.3 Differences in data compilation, definitions, and extent of CSAs

An important variable in the ALTERFOR results interpretation is the number of tree species within each CSA. This information can be used for assessment of changes within, or comparison between CSAs for example. However, it can be biased due to different countries' species grouping in their forest inventory and simulation data. For example, the large number of species in Slovakia compared to Germany is simply due in part to their more detailed tree species registration. Furthermore, such variables will of course also vary in response to the size of the CSA. A prime example of this is that the Dutch CSA encompasses the entire 3.7 million ha of the Netherlands, whereas the Portuguese CSA is only 15,000 ha in size. Likewise, differences in understory conditions are not only likely to reflect management history and site conditions, but also the different definitions being applied across CSAs. For example, the understory definition applied in Germany is presumably more broadly defined than that applied in Slovakia.

6.4 Balancing the need for realism and result differentiation

One of the notable results across CSAs was the limited difference in outcomes under the three global frame scenarios (Reference, EU Bioenergy, Global Bioenergy) within each country. In those countries where differences were observed between global frame scenarios, these differences could be tied to the requirements of the scenarios themselves. For example, the highest harvest volumes were evident in the Global Bioenergy scenario (and EU Bioenergy, Slovakia) and lowest in the Reference scenario, which is in keeping with the frame scenarios' internal assumptions for wood demand. Given substantial climatic change (i.e., Reference scenario) and the associated differences in assortment price changes relative to those provided under the limited climate change in the Global Bioenergy scenario, the expectation was for more substantial divergence in result outcomes. Correspondingly, in those countries (e.g. Sweden) in which the uptake of suitable aFMMs to match timber demand was coupled to the appropriate scenario, one does see more substantial differences in ES provision

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between the climate scenarios, though still within the constraints of time lags in forest development. Likewise, and correspondingly, the climate scenarios applied did not cause fundamental differences in the Ecosystem Service outputs at the case study level over the time frames assessed.

These results may simply stem from the gradual nature of the projected temperature increases that underlie the scenarios, however additional explanations are possible. First, forests may be sufficiently adapted to the projected levels of climate change. In this regard, some aFMMs included tree species shifts in order to actively promote adapted tree species compositions. Second, the management regimes applied, including the introduction of the aFMMs, may make sufficient allowance for climate and market changes, to result in similar levels of e.g. timber provision in the three global frame scenarios. Third, in some CSAs the effect of climate change as modelled (i.e., mainly as a temperature increase) had positive effects on growth in the Reference scenario but limited it in the Global Bioenergy scenario, which together may have reduced differences in outcomes. In either regard, as the climate aspect of the global frame scenarios assumes gradual change, the strongest deviations from the current climate occur around the end of the 100-year forecasting period, and any shift in climate towards the edge of a tree species' ecological comfort proceeds slowly in the analyses, with resultant implications for outcomes.

In contrast, in those case study areas where several forest management scenarios were implemented independently of climate scenarios the differences among these in biodiversity and ES outcomes were generally more pronounced than those driven by climatic differences, despite the fact that there is often a transition period from the current state to a future state formed by the aFMMs. In other words, just as climate change impacts are more extensive by the end of the century, so too are there delays in the rate at which aFMMs can be implemented and have their full effect, and the time taken for the impact of these changes to reveal their full or even partial implications. For this reason, some outcomes, including risk impacts, could be usefully divided into near future (ca 30 years) versus longer term (100 years) implications.

6.5 Ongoing limitations in the capacity to incorporate climate change associated risks in assessments

The regulatory services assessed in ALTERFOR related exclusively to the capacity of management to mitigate the risk of calamities occurring, and not, for instance, risks stemming from uncertainties in terms of which climate scenario will prevail, or from the impact of input data errors. Ideally, one would analyse risk in terms of the potential or likely loss due to risk factors like wind throw, wild-fires or pest outbreaks. This calculation would preferably be done based on the configuration of landscape features. For example, production forest edges that are at higher risk of wind throw, or contiguous forest areas that are more prone to wild-fires, etc. However, risk is a complex phenomenon in several respects. The predictive power of probabilistic models for risk are in many cases weak, or such models have not as yet been sufficiently developed for our purposes. Even if a reliable model was available, the complexities of calculating the impact of a risk factor increase dramatically when projecting outcomes or an entire landscape over a long time horizon, as was the case in ALTERFOR. Thus, in many cases our risk assessments had to be based on expert judgement and categorical classifications of risk, rather than one provided by an empirically based risk assessment model. Spatial landscape

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analyses were also an exception rather than the rule, with the result that risk assessments were generally based on the sum of stand characteristics, or otherwise aggregated landscape measures without localized information.

Furthermore, it is entirely possible, if not probable, that the models and data used in forecasts did not fully reflect the seriousness of the impact that the climate will have on production forests and timber provision of the forests in the future. While climate change seems to be reasonably covered by the models as far as the average annual climate characteristics are concerned, the projection of extreme events (e.g., pronounced droughts, fires, storms) remains problematic. The frequency and severity of such events may increase dramatically in the future, which could potentially have a drastic impact on large forest areas, the habitats they support, and the Ecosystem Services that they provide. However, such effects are neither included in the global frame scenarios, nor are they readily implemented in the management-oriented forest growth and silvicultural models of many of the participating CSAs. In this regard, it is notable that the more extreme climate change scenario Reference did not generally lead to higher risk levels than the more modest climate scenarios. If one wished to take this positively, it could be interpreted as a function of the fact that the aFMMs implemented were designed to promote sustainability, which in many cases mitigated some risks. However, this outcome can also be explained by limited knowledge regarding the frequency and severity of future wind, drought and other hazards. The fact that none of the risk assessments explicitly account for this possibility makes it yet another point of precaution when interpreting the results. It is important to keep in mind the implications of this point, including the important feedbacks this had in relation to projected levels of carbon sequestration and the resultant climate change mitigation contribution of Europe's forests.

6.6 Use diversity metrics where beneficial, but know their limitations

The number of tree species can be informative for CSA comparative assessments, and when comparing the outcomes of simulations involving different climate change scenarios or FMM implementation. This simple piece of data provides a readily interpretable metric for stakeholders and scientists alike. However, diversity indices can provide additional benefits. In ALTERFOR, we used the Shannon Diversity Index H, which allowed us to express tree species diversity at the CSA level, using the number of species and the species volume shares. Thus, higher Shannon Diversity scores relied upon both the number of tree species (more species equals a higher score), and the more balanced share of the species' volumes (more balanced shares equals a higher score). Using volume shares in assessments helps to ensure that the occurrence of species added or established on additional areas, which may be numerous in individuals but negligible in biomass, did not simultaneously misleadingly inflate result outcomes. That said, whereas the Shannon index provides a useful theory-based concept for diversity assessment, it might be affected by a potential reporting bias of the tree species numbers. In order to reduce this bias as much as possible, and in order to provide a raw underpinnings of the Shannon index for result interpretation, we found it beneficial to also calculate an Evenness indicator.

The Evenness indicator E is the ratio of the actual Shannon Index H to its theoretical maximum, which is calculated in this case using the theoretical maximum for the number of tree species in the region of interest. As a result, the Evenness indicator has the distinct advantage of allowing Shannon values from different regions possessing different natural species abundance to be equilibrated so as to make them comparable with one another. In order to do so efficiently and consistently for each CSA,

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we took the greatest number of tree species obtained in any scenario and used it as a proxy for the maximum potential number of species.

6.7 The development of a carbon evaluation tool for cross national comparison

A generic methodological framework was developed and implemented in R script to provide a harmonised approach to assessing C sequestration across the different CSAs (Biber and Black, 2018, see also D3.2 (ALTERFOR WP3 Leaders 2018c) for details). The carbon evaluation tool developed in ALTERFOR (Biber and Black 2018) allowed estimates of the most important carbon stocks in the forest, including harvested wood products and substitution effects resulting from the use of wood instead of other raw materials (e.g. concrete). The carbon balances of these components can likewise be evaluated separately and added up to the total carbon balance of the forest area of interest. We also used the International Panel for Climate Change (IPCC) default for C stock changes in mineral soils to enable cross country comparison, using a zero standard for managed forests where relevant (IPCC, 2006). In cases where there are organic soils within a CSA, such as study area in Ireland, the default IPCC emission factors for drainage of organic soils (0.61 tC/ha/yr) and run-off emission from DOC (0.31 tC/ha/yr) were considered as part of the forest C balance (IPCC 2006). Organic soil emissions were not included in the generic modelling framework provided to all CSAs, except in cases like Ireland, for which most forest soils were organic.

In order to further evaluate differences in carbon sequestration across CSAs and global frame scenarios, forest mensuration and C sequestration variables were standardized and expressed as a value per ha. An important point remains however with the spatial scale of the assessment. The results for the CCF managed forest in Turkey (aFMMs) resulted in a large increase in C sequestration potential when compared to the current FMMs. These findings contrasted with those of other studies (e.g. Lundmark et al., 2016), which show that C sequestration does not differ between continuous cover forestry versus conventional even-aged plantation forest management. However, and central to our point, the study by Lundmark et al. (2016) was done using a stand-based model. In contrast to landscape models, stand models do not consider the effect of shifts in age class structure in the landscape (which are automatically covered with the ALTERFOR approach), and their resultant implications for overall C balance. This is an important point to consider when evaluating study outcomes.

6.8 Importance of involving practitioners

The German approach to evaluating risk outcomes revealed an important point with wider scale implications regarding the importance of involving practitioners at all stages of the modelling process. At first the applied simulations only revealed small differences between global frame scenarios for a given set of aFMMs. As importantly, the risk scores applied to different forest types made by local forest managers, differed somewhat from the standardized literature and practitioner-guideline driven assessments. Controversial conclusions that stemmed from these differences included (i) stand structural diversity decreasing fire risk (which traditionally were seen as a risk factor, due to understory and subdominant trees acting as fire ladders), (ii) deadwood increased fire risk significantly (which was challenged by nature protection representatives), and (iii) high shares of Scots pine, regardless of tree sizes, were associated with high fire risk. By incorporating the experiences of local practitioners, outcomes of distinct aFMM strategies were amended to incorporate the wider range of knowledge

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available, with important implications for outcomes and how distinct silvicultural alternatives could be ranked in terms of costs and benefits.

6.9 Fuzzy logic

Despite the large number of variables that dictated the response of many CSAs to the global scenarios considered, there was often general consistency with respect to which patterns of change were considered positive with respect to achieving goals for biodiversity and many of the Ecosystem Services. Using the biodiversity outcomes as a representative example, despite the extensive biogeographical, political and silvicultural differences between nations, we found that increasing the availability of key forest structures (e.g. large trees, dead wood), raising the diversity of tree species composition, and minimizing the use of introduced tree species, did turn out to be agreed upon and consistent strategies for achieving regional biodiversity goals across the CSAs. Because of this, we see the Fuzzy Logic approach used in the German CSAs as a highly promising standardized means of integrating and interpreting such outcomes for cross-country comparisons.

To do so we built on the work of Blattert et al. (2017), who proposes a promising approach based on utility theory whereby values of forest (structure) indicator variables are mapped by way of utility functions to a dimensionless score between 0 and 1. In this case, 0 indicating the least desirable, and 1 indicating the best available performance in terms of Ecosystem Service provision. With our approach, we suggest a complementary way for the same mapping task, based on fuzzy logic. The concept of fuzzy logic, introduced by Zadeh (1965), has a few key properties that seem to make it ideal for the task at hand. As fuzzy logic systems incorporate the “blurred”, i.e. fuzzy reasoning of the human mind, they are useful for robustly mimicking the way experts develop qualitative assessments of a given situation. The reasoning implemented in fuzzy logic systems is always based on rules which should be defined by experts. In other words, the rule set of a fuzzy logic system is in effect consolidated expert knowledge. Such rule-based setups have an important advantage in forest decision making guided towards desired levels of Ecosystem Service provision. To form an opinion about a given situation and/or proposed alternatives, decision makers and stakeholders generally require a small set of key information which has to be boiled down from a complex set of inputs. However, the way this “boiling down” takes place must be readily understood and modifiable in order to justify confidence. This is especially important for Ecosystem Services where what is considered adequate or sought after Ecosystem Services provision, strongly depends on stakeholder perceptions, which may require that alternative value judgements are included in the assessment. As fuzzy rule formulations can directly reflect human valuation processes (e.g. IF in a forest landscape the volume share of Scots pine is high AND if there is much understorey AND young stands dominate THEN the risk of forest fires is high), they can be easily communicated to and discussed with non-scientist stakeholders and decision makers. We deem this transparency a valuable asset in such discussions and potential policy formulation.

More information:

- ALTERFOR deliverables: https://alterfor-project.eu/wp3.html
- Deliverable 3.3 – Proceedings from open workshop
- Deliverable 3.4 – Synthesis report: New FMMs in a landscape perspective: Innovation needs and gains in ES provisioning

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- Biber, P., Felton, A., Nieuwenhuis, M., Lindbladh, M., Black, K., Bahyl J., Bingöl, Ö., Borges, J.G., Botequim, B., Bugalho, M., Corradini, G., Eriksson, L.O., Forsell N., Hengeveld, G. M., Hoogstra-Klein, M.A., Kadıoğulları, A.İ., Karahalil, U., Lodin, I., Lundholm, A., Makrickienė, E., Masiero, M., Mozgeris, G., Pivoriūnas, N., Poschenrieder, W., Pretzsch, H., Sedmak, R., Tucek, J., (2020). Forest Biodi-versity, Carbon Sequestration, and Wood Production: Modelling Synergies and Trade-Offs for Ten Forest Landscapes across Europe, Frontiers Ecology And Evolution, Submitted Paper.

7. Global models

In ALTEFOR, we **applied global models additionally to analyse the long-term impacts of a large-scale uptake of alternative Forest Management Models** (here aFMMs) within the **EU28** on different **Ecosystem Services**. We considered the impacts on different services, including the production of harvest wood products by the forest based industrial sector, the implications on biodiversity within and outside of Europe and the forest carbon sink in Europe. The results of our assessment provide important information for policy makers on the possible **effects** of implementing aFMMs across large areas of European forests.

7.1 Methods used in global models

The analyses in WP2 “European Analyses” were based on the Global Biosphere Management Model (GLOBIOM) and the Global Forest Model (G4M).

GLOBIOM is a global spatially explicit partial equilibrium economic model of agricultural and forest sectors. The model was updated to include three different categories of aFMMs: production forest management (PFM), multifunctional forest management (MFM) and set-aside forest management (SAFM).

The parameterization of these management categories was based on the results of the 9 case studies and the landscape simulations performed in the ALTERFOR project (i.e. Germany, Ireland, Italy, Lithuania, Netherlands, Portugal, Slovakia, Sweden). The landscape models from the different countries provided information about the impact of implementing the different aFMMs, as compared to the current management. These results were then aggregated to a stylized representation of the aFMMs and classified into the three broader categories of Alternative Forest Management (PFM, SAFM, MFM). PFM included managements increasing wood harvest compared to the current management. MFM included managements reducing wood harvest compared to current ones and promoting other services. SAFM included set-aside management.

The suitable areas for the different aFMMs, outside the case study areas, were based on a suitability index developed together with ALTEFOR Work Package 3 that indicates how similar an area is to that of the case study areas. The suitability index was obtained by comparing each case study area to similar forest areas across the whole EU28. As the suitability index does not define how quickly we can mobilize the forest owners to implement the aFMMs, GLOBIOM only assumed that all suitable areas can be successfully converted by the year 2100. This implies that aFMMs could theoretically be

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implemented in 79 Million ha of forests within the EU28, which corresponds to about 50% of the total forest area in EU28. For our assessments, it was further assumed that the suitable area for the aFMMs could grow linearly from zero in 2020 to the total suitable area by 2100. This constraint was added in the model to avoid a fast transition to aFMMs in the simulations over time. For the area not considered suitable for aFMMs, we applied the continuation of current management practices with constant tree species distribution.

The GLOBIOM model was used in economic simulations until the year 2100, observing the development under different scenarios at a 10 year-time step. Two climate change-mitigation-scenarios, respectively the RCP8.5 and RCP2.6 were considered along with one socioeconomic development scenario (SSP2). RCP8.5 is the no-mitigation (zero carbon price) scenario leading to a 3.8 °C temperature increase in year 2100 compared to the pre-industrial level. RCP2.6 is the high mitigation scenario leading to a 1.8 °C temperature increase in year 2100 compared to the pre-industrial level. SSP2 is the "middle of the road" scenario with intermediate socio-economic development. The two climate mitigation scenarios lead to different developments of wood demand in GLOBIOM under the SSP2. Nested in the two climate mitigation scenarios, we considered 10 different forest management scenarios, these were obtained as a combination of current management and forcing a gradual expansion of Alternative Forest Managements (PFM, MFM, SAFM) in the EU28 until the year 2100. The management scenarios included a "Baseline" scenario without aFMM, which is a continuation of current management under economic optimization. In one of the alternatives, known as "aFMMfree", forest owners could choose freely between aFMMs and current managements (FMM). In this case, the only competitive aFMM relative to current management practices was the PFM, since MFM/SAFM decreased available harvest volumes. In the remaining scenarios, forest owners were forced to uptake MFM/SAFM for a different percentage of suitable areas whereas for the remaining share of suitable area they could choose freely between current management and aFMM.

In our analysis, we focused firstly on the economic trade-offs between current managements and aFMMs. We considered compensation payments for forest owners for the lost production value of forests. Such compensations are more generally called payments for Ecosystem Services. In addition to compensation costs, we considered also the potential leakage effect of implementing the aFMM on harvests of wood, forest industry production and bioenergy feedstocks. The assessment of leakage effects thereby assesses how the implementation of aFMMs may cause the production of harvest wood products to move from within the EU to outside of the EU.

An assessment of biodiversity impact of different management scenarios was obtained by considering the intensity of forest land management and how this is impacted by implementing aFMMs. For this assessment, the forest management area results of GLOBIOM scenario runs were coupled with Characterization Factors (CFs). These factors are indicating the "potential loss of global species" (i.e. extinction of vertebrate taxa and vascular plants) per unit area under each forest management in a particular geographical region (ecoregion), when compared to pristine land cover (pristine forests). Therefore, by multiplying the forest management area of each FMM/aFMM by the respective CFs we were able to assess the potential species losses as a function of the different forest management applied in each area of forest under management around the world.

The Global Forest Model (G4M) was used for a more detailed projection of wood harvest and carbon sink under the uptake of aFMMs and compared our results to previous "Forest Reference Level" carbon sink projections for the next decade (years from 2021 to 2030). The simulations were performed

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under the condition that the different countries should still match the wood harvest levels estimated for their Forest Reference Levels as close as possible. A representation of the aFMMs, as clear-cut, selective logging, shelterwood logging and tree species change was included in the G4M. The aFMMs were modeled in G4M under four scenarios of spatial allocation and two scenarios of uptake rate which were compared with the Business as usual scenario. The four spatial allocation scenarios considered in G4M were: Production forestry (aFMMs aimed at wood production were prioritized); Multifunctional forestry (aFMMs aimed at multifunctional forest use were prioritized); Balanced forestry (all aFMMs were promoted equally); Set-aside forestry (aFMMs aimed at biodiversity, wilderness, restoration, stand edge management and other nature protection low-intensity management were promoted). The G4M uptake scenarios compared immediate introduction of aFMMs in 2020 and the gradual introduction of aFMMs between 2020 and 2030).

7.2 Alternative FMMs uptake on a large scale improves internal EU benefits but could create leakages in other Regions

The results of our assessment indicate that a transition to MFM (Multifunctional Forest Management models) or SAFM (Set Aside Forest Management models) tends to imply leakage effects on harvests, forest industry production and bioenergy feedstocks outside Europe. Our results confirm the finding of previous studies that transition to SAFM would imply considerable leakage effects. The new finding of our assessment is that transition to MFM implies much **lower leakage effects than SAFMs**, because EU28 forest industry can substitute coniferous biomass use by non-coniferous biomass. This substitution is not possible in the SAFM transition, as SAFM decreases both coniferous and non-coniferous harvests (Figure 12).

The leakage effect on forest industry production and bioenergy feedstocks depends on the possibility to compensate lower domestic harvests by import. If EU28 can increase roundwood imports sufficiently (e.g. from Russia or other nearby areas), then the leakage effect on EU28 forest industry and employment remains small. The leakage effect on bioenergy feedstocks is small in the RCP8.5 scenario, but it leads to considerable increase of pellet import to EU28 in the RCP2.6 climate mitigation scenario. If EU28 cannot increase pellets import sufficiently, then the decrease in logging residues and forest industry by-products is compensated by domestic energy crops. Increasing EU28 energy crops production is possible, but it might reduce food security in the agricultural sector due to the land use competition between energy crops and cropland.

The economic results indicate also that forest owners apply voluntarily PFM (highly Productive alternative Forest Management models) while they do not apply MFM or SAFM without additional compensation payments, as these managements decrease the harvest potential and expected income from wood sales. The estimated average payments for a full transition, where 100% of suitable area is converted to MFM or SAFM, are 150 €/ha/yr and 500 €/ha/yr, respectively. This difference is due to the major economic losses in the SAFMs management compared to MFMs. The payments are substantially lower in a partial transition, where 25-75% of suitable area is converted to MFM or SAFM and the rest of the suitable area being converted to PFM. For this reason, scenarios combining PFM, MFM, SAFM would be preferable from a forest owner perspective.

In terms of biodiversity, MFMs and SAFMs uptake on large forest areas appears reducing the species losses due to the EU28 land use, particularly under a scenario of high mitigation demand (RCP2.6). On the other hand, if considering the global biodiversity footprint of the EU28 (i.e. due to internal

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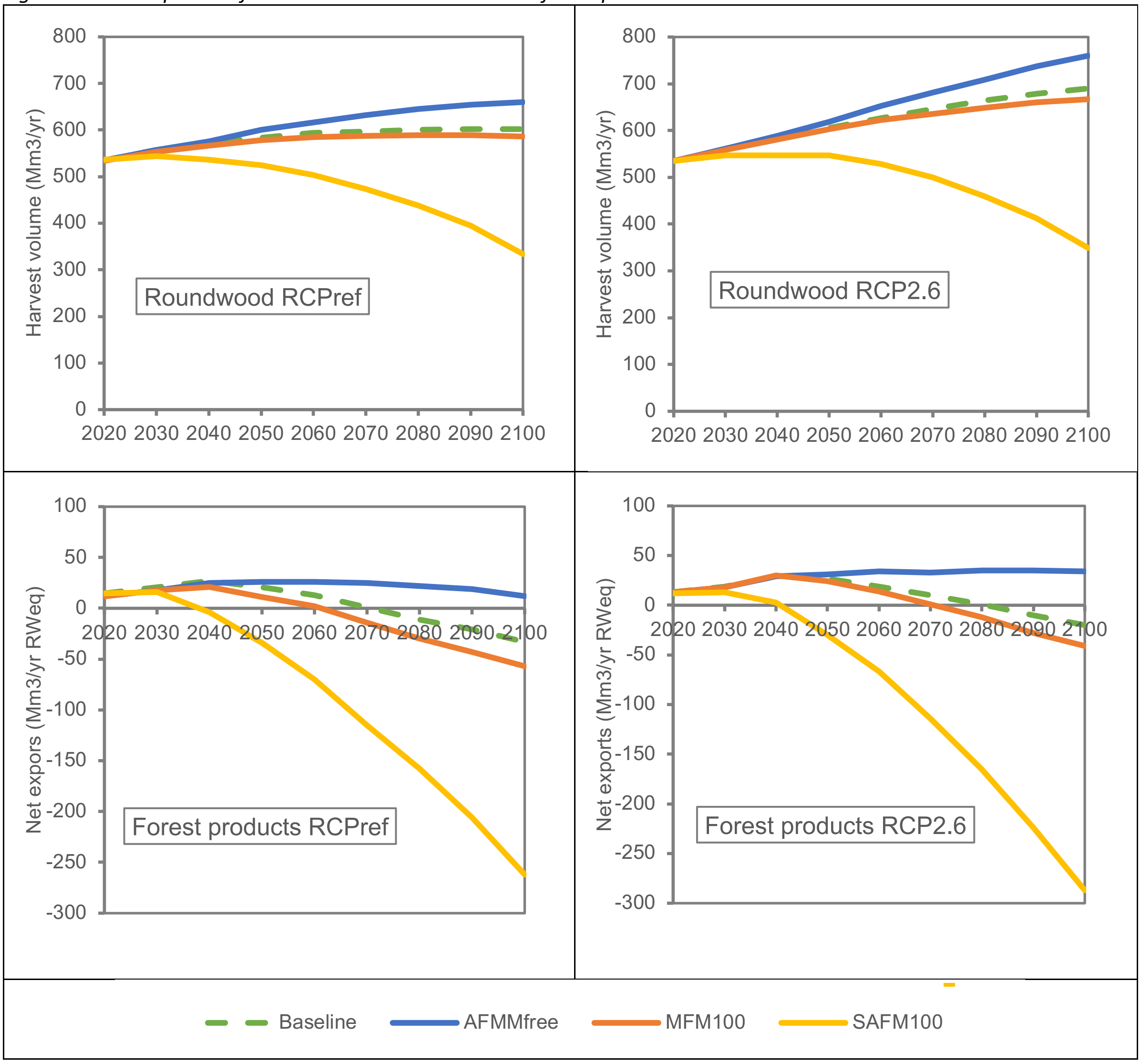
land use and forest sector imports), the aFMM free with uptake of PFMs on large surfaces appears to perform better than MFM and SAFM, and allowing significant reductions of species losses. Therefore, as for the forest sector economy and for biodiversity there is a trade-off between internal uptake of MFMs/SFMs on large areas and external leakages through imports (Figure 12).

Figure 12. Development of EU28 roundwood harvests and forest products net



EU28 roundwood harvests (top) and forest products net exports (bottom) development for different aFMMs uptake scenarios (baseline, aFMMfree, MFM100, SAFM100), under two different climate mitigation scenarios (RCPref, RCP2.6).

In particular, the expansion of SAFMs on a large share of European forests produces more positive results than MFMs in terms of biodiversity losses due to internal land uses but would worsens the EU global footprint, as an effect of the higher import to the EU28 (Figure 12).

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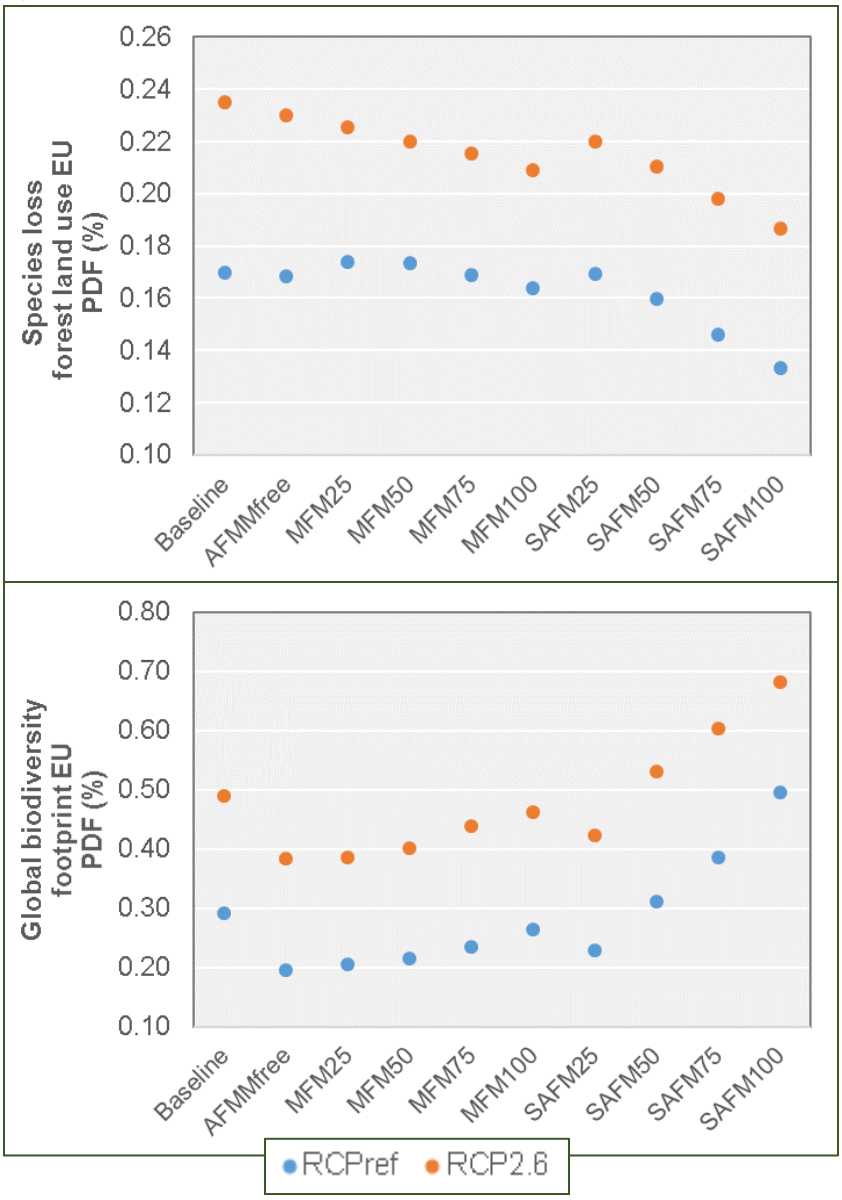
Figure 13. GLOBIOM scenarios – Results



Results for the GLOBIOM scenarios in the year 2100 for "Potential global species loss" due to forest land use in the EU28 (top) and global footprint of EU28 (bottom). The results are presented under two different climate scenarios (RCPref, RCP 2.6) and for ten different scenarios of AFMMs uptake (MFM0-100, SAFM0-100).

The introduction of the aFMMs enhances also the **forest carbon sink** during 2021 – 2030 in all studied regions within the EU member states and Turkey, if compared to the business as usual (i.e. continuation of current management models). The detailed results suggest that if a balanced mixture of aFMMs is chosen, a similar level of wood harvest can be maintained as the one in the Forest Reference Level projections, while at the same time enhancing the forest sink. In particular, a mixture of multifunctional aFMMs, like the ones based on selective logging and shelterwood, could enhance carbon sink up to 21% over the ALTERFOR region while limiting harvest leakages.

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In conclusion, due to lower forest industry leakage effects, compensation costs and overall biodiversity footprint, the different MFMs can be considered a better option to produce wood and other Ecosystem Services in the EU28 than SAFMs, or a combination of SAFM and PFM. Moreover, MFM is also a less risky option to produce these services, as SAFM and PFM tend to be more vulnerable to natural disturbances than MFM. In addition, an optimal combination of MFMs would allow to further enhance the forest carbon sink in the next decade while limiting wood harvest leakages.

7.3 Scientific Limitations

There were some limitations in upscaling from the case studies to the global models being used for this assessment, because the latter required a parametrization under more “stylized” representation of the original aFMMs under the three broader categories. This required a series of assumptions for allowing a classification of aFMMs under the broader categories adopted for this analysis. Thus, we acknowledge that some of the aFMMs could not be fully represented within the global model given their very specific aims (e.g. oak for cork management in Portugal).

There was also some inconsistency in the initial set up of aFMMs across the case studies. For example, some case studies included MFMs, but not PFMs and SAFMs. In these cases, for a consistent simulation, the missing data for PFM and SAFM was created using data from other but similar case study areas.

Another limitation of the study was that suitable area for the different types of aFMMs (PFM, SAFM, MFM) was assumed the same and covered only 50% of EU28 total forest area. For the remaining area, we applied the continuation of current management practices with constant tree species distribution. This was assumed as information concerning the suitable areas for different tree species and alternative managements was not developed within this project. This increased somewhat the opportunity costs of MFM and SAFM, because in the GLOBIOM modelling framework it was not possible to compensate MFM and SAFM by applying PFM in the remaining areas. Therefore, extending suitable area for the whole EU28 forest area, and also forest areas outside EU28, would be an important subject for future studies. For example, if other regions than Europe apply aFMMs, then the leakage effect of implementing aFMM within the EU28 would be different. This issue was not considered in this specific study and we assumed that the regions outside EU28 would not shift to alternative forest management.

Another shortcoming in our analyses is that compensations to forest owners were based on the opportunity costs of aFMM, i.e., we did not account for the non-market benefits of other Ecosystem Services and improved resilience of forests against climate risks. This means that we might have overestimated the compensation costs of transition to aFMMs. Therefore, including the social value of other Ecosystem Services and the “insurance effect” of improved resilience of forests against climate risks in the analysis would be an important subject of future studies.

In addition, all indirect land use change effects due to changes of forest management were excluded from our analyses. An example of such indirect effects could be the increase of areas of energy plantations on agricultural land used for compensating a reduced wood supply from forest management. This type of leakages could potentially cause indirect deforestation through the relocation of agricultural land in order to satisfy the food demand. Also, these aspects could potentially be analyzed through follow up analyses.

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Given the time horizons considered in our large-scale analyses, the results of our assessment are valid for long time development of forest resources since our models are not fully able to represent the short time dynamics of forest ecosystems, but rather assess the long-term implications. However, thanks to these models, a decision maker could still receive a quantitative advice on different choices, based on the relative difference between the different simulation scenarios obtained under a consistent modeling framework.

More information:

- ALTERFOR deliverables: https://alterfor-project.eu/wp2.html
- ALTERFOR Deliverable 2.1: Impact assessment of FMM for the forest sector
- ALTERFOR Deliverable 2.2: Impact assessment of FMM across sectors
- ALTERFOR Deliverable 2.3: Impact assessment of FMM across ES
- IRELAND: Lundholm et al. (2019). Implementing Climate Change and Associated Future Timber Price Trends in a Decision Support System Designed for Irish Forest Management and Applied to Ireland's Western Peatland Forests; https://www.mdpi.com/1999-4907/10/3/270

8. Facilitating implementation of FMMs by stake holder analysis and involvement

Implementation of FMMs can only happen if specific actors adapt their forest management and/or renew their policy tools in order to support innovative forest management.

ALTERFOR facilitated capacity building for FMMs by (i) drawing attention to a broad range of actors, (iii) evaluate their different capacities to elicit political support and (iii) link them with support for specific FFM alternatives.

8.1 Broad range of actors

Table 3 shows that ALTERFOR was successful in **involving a broad range of actors** from practice: One can see that all actor groups were represented in ALTERFOR workshops, being used to integrate results on FMMs into the forest-based practice.

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Table 3. Number of participants in ALTERFOR workshops per country and actor group

Countries	Actor groups										ALTERFOR*
	General public administration	Public forest administr. /managem.	Private forest owners, companies	Nature&environm. protection administr.	Other state/public organis.	Timber industry, wood retailers	Hunting associations	Outdor recreation	Nature and envir. protection associat.	Other	
	PA	FA	FO	NCA	OP	TI	H-OIG	R-OIG	NC-OIG	O	
Germany (GER)	0	41	7	1	12	3	1	0	10	5	20
Ireland (IRL)	0	4	1	3	3	0	0	1	0	0	8
Italy (IT)	6	10	2	0	0	0	0	13	2	86	12
Lithuania (LT)	0	88	5	13	0	25	0	0	0	104	12
Netherlands (NL)	0	6	6	0	8	0	0	0	1	2	5
Portugal (PT)	0	9	26	0	1	13	0	0	7	7	15
Slovak Republic (SR)	0	15	3	23	0	0	0	0	0	28	10
Sweden (SWE)	0	5	8	3	0	6	0	0	0	2	11
Turkey (TR)	0	50	2	7	8	5	0	0	1	8	15
TOTAL:	6	228	60	50	32	52	1	14	21	242	108
	0.8%	*32.3%*	*8.5%*	*7.1%*	*4.5%*	*7.4%*	*0,1%*	*1.9%*	*3%*	*34.2%*	
	706 *(100%)*										108

Source: ALTERFOR Deliverable D4.2

*****One separate group is ALTERFOR project participants, 108 in total. This number of participants is not to be mixed with the number of persons, e.g. in Germany there were five persons visiting four workshops, which makes 20 ALTERFOR participants together. **Legend**: PA – Public Administration; FA – Forest Administration; FO – Forest Owners; NCA – Nature Conservation Administration; OP – Other Public; TI – Timber Industry; NGO – Hunting (H), Recreation (R), Nature Conservation (NC) Associations; OIG – Organized Interest Group; O – Other.

The share of workshop participants from the public forest administration and/or organizations managing federal/state/municipal forests in respective CSAs is amongst the highest (32.3%), which together with the private forest owners (8.5%) and timber industry (7.4%) makes nearly the half (48.2%) of participants. Another half is constituted of nature and environment protection agencies (7.1%), general (0.8%) and other state/public agencies (4.5%), organized interest groups of nature conservation (3%) and recreation (1.9%) (NC-OIG) or Others (34%) like media or students.

8.2 Set of political steering instruments and links to FMMs

ALTERFOR aims to facilitate implementation of FMMs and the key to implementation is the **linking of FMMs with the political** instruments. Instruments, pushing the practice toward actions in the forest, are those having an effect on forest management. Instruments can be divided into

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informational, economic and regulatory (Krott, 2005). Each can further be used either within the hierarchal intervention (=**government**) or within a non-hierarchical negotiation (=**governance**), which taken together give six types of instruments for political steering (❶ - ❻, Table 4). In the **Table 4 all follow-up activities identified within the ALTERFOR project** (Deliverable D4.2) are assigned to one of this six groups (governance in the left part and government in the right part of the table), together with the actors implementing them in practice.

Table 4. Groups of actors and follow-up activities within governance and government steering

Political steering	
Governance (non-hierarchical negotiation)	Government (hierarchical intervention)
Informational instruments *and groups of actors implementing them*	
❶ *Delivering strategic options for action *Demonstration site / FM guideline *Follow-up discussions / model improvement *Joint article / book *Cooperation with regional / other research *Future applied, collaborative research *Follow-up events *Serving specific information needs of actors *Linking with national policy windows *Triggering resistance	❷ *Further develop research activities *Use of aFFM projections for national cases *National web page
Forest Administration *(10 cases),* ***Forest Owners*** *(8 cases),* ***Other Public*** *agencies (7 cases),* ***Nature Conservation Administration*** *(4),* ***Other*** *(4 cases),* ***Organisad interest groups in nature conservation NC-OIG*** *(2cases), Organised interest Groups in recreation* ***R-NGO*** *(1 case),* ***Timber industry*** *(1 case)*	***Other Public agencies*** *(2 cases),* ***Forest Administration*** *(1 case)*
Economic instruments *and groups of actors implementing them*	
❸ *Develop forest policy to allow aFFM impl. * Cooperation with regional market actors	❹ /
Forest Administration *(1 case),* ***Forest Owners*** *(1 case)*	/
Regulatory instruments *and groups of actors implementing them*	
❺ *Develop forest policy to allow aFFM impl.	❻ *Triggering resistance *National sites for implementation
Forest administration *(1 case)*	***Forest Administration*** *(1 case),* ***Nature Conservation Administration*** *(1 case)*

Sources: Krott, 2005 & Krott, 2008 (modified) & ALTERFOR CSA workshop documentations & ALTERFOR meetings Padua, Dresden; ALTERFOR Deliverable D 4.2, modified.

Legend: FA – Forest Administration; FO – Forest Owner associations; NCA – Nature Conservation Administration; TI – Timber Industry; OP – Other (specialised) Public Organisations; NGO – Nature Conservation (NC), Hunting (H), Recreation(R) Associations; O – Other

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As one can see from Table 4, **majority of activities belong to the informational instruments**, followed by regulatory and economic ones. Within the informational instrument type, it is 10 activities under governance (❶) and 3 under government steering (❷). As the steering compulsoriness increases from ❶ to ❻ (by following definition of Krott 2005, compulsoriness is increasing from informational governance to regulatory government instruments), one can conclude that the most follow-up activities belong to the **non-compulsory** informational instruments (Table 4).

8.3 Involvement of actors from practice

ALTERFOR assumes that enhanced **scientific knowledge on aFMMs will not automatically lead to its adoption in practice** and aims to facilitate the process of transferring information on modelling results to the actors in particular CSAs and so **enhance implementation potential** for FMM alternatives.

Actors from practice can be approached by multiple means. All these activities, linking scientific results with the actors from practice, have to be **embedded into the specific social, economic and political environment.** ALTERFOR did these based on the local knowledge of the CSA coordinators.

The most important mean of involvement are **bilateral contacts** of researchers to the actors in practice (Böcher and Krott, 2016). These contacts have to be developed over a long period of time and cannot emerge quickly, in the moment when a project is planned or result has to be presented.

One of the frequently applied means is a **workshop.** The ALTERFOR workshops were planned to present selected research findings about aFMMs to the actors in each CSA. In total **20** workshops took place from September **2017** to December **2018** (deliverable D4.2). The **success factors** for the workshop concept were defined in ALTERFOR Milestone 17, which served as a basis for national case coordinators by planning, organizing, implementing and workshop reporting:

- Links to current forest policy issues in each CSA
- Links to multiple competing powerful actors
- Alternative FMMs and pathways for different actors
- Support of non-academic partners by the preparation and organization
- Hosting the workshops by the actors from practice
- Alternative workshops for different advocacy coalitions
- Alternative workshops for different political-administrative levels

8.4 Travellab – learning while travelling

Most collaborative research projects organise their consortia meetings in format of traditional scientific conferences. This implies lengthy and often tiring sessions of PowerPoint presentations, at best complemented with an optional excursion. In ALTERFOR we departed from such conventions by adopting the Travellab approach, an **innovative format for learning while travelling**.

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Instead of a conventional excursion, Travellab contains a **targeted field trip where scientists meet local stakeholders** and see concrete examples of implementing different approaches to forest management. The **field trip** is preceded by a preparatory session illuminating local and national contexts; and complemented by a **round-table session** where stakeholders and scientists debate hot forestry topics. Travellab thus goes well beyond narrow technical discussion of certain silvicultural method or modelling technique, providing important insights into socio-economic contexts, stakeholders' power and interests, and the overall capacity to implement alternative forest management. The format was first tested in Zvolen, Slovakia (2016) and, following the successful event, implemented in Galway, Ireland (2017), Porto, Portugal (2018) and Veneto, Italy (2019).

"The travellab was insightful. Increased understanding for the Slovakian situation, and sparked discussion between other CS-participants on how things are organised in their countries."

"Very useful field trip in order to put into real context the alterfor simulation activities and assess the degree of realism of scenarios and their overlap with silvicultural options and real problems highlighted by foresters."

"I thought it was very interesting and educational. The different prescriptions and goals with each forest stand was clearly articulated. I think the discussions were good and it became clear that they think differently about forestry […]"

"This activity was very interesting for me. It put the Slovakian forest management models in a natural and social context that is hard to perceive from the "office"."

"Travellab is well organised and also conducted as desired. I think Travellab was started on previous day by explanations of the current FMMs in the CSA and general overlook to the Slovakian forestry given by Robert. Selected FMMs were seen on the field with different management regimes. Diverse forest structures were also observed as a result of those different FMMs. […] Round table discussion was also interesting for creating the opportunity in putting together the stakeholders such as state, owners, contractors and researchers."

"My impression is that Travellab idea in general is indeed perfect. I liked also the structure of the Travellab provided in the guide. I feel that the first Travellab conducted in Slovakia was a good start to deepen the mutual communication between science and forestry practice in the future."

We found that Travellab served its intended purposes very well and could be a suitable meeting format for many European research projects, not least those, adopting the multi-actor approach[3]. The exact set-up of a Travellab would of course depend on the purpose and profile of the project in question[4], but, as a guiding principle, consortia meetings an international collaborative projects offer excellent opportunities for learning through seeing the local contexts, meeting the local stakeholders and cross-fertilising scientific and practical knowledge. In case meetings are confined to Powerpoint marathons, it would be high time to ask the question whether virtual sessions would suffice, sparing all the travel time and carbon footprint.

[3] Multi-actor approach is has been adopted in many Horizon2020 projects, meaning that a project must focus on real problems or opportunities and that partners with complementary types of knowledge – scientific, practical and other – must join forces in the project activities from beginning to end.

[4] For another example of a Travellab format see: Feliciano, D., Blagojević, D., et al. (2019). Learning about forest ownership and management issues in Europe while travelling: The Travellab approach. *Forest policy and economics*, *99*, pp.32-42.

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More information:

- On the project website, information on the Travellab sessions and specifics of the case study areas where the excursions were organised (Slovakia, Ireland, Portugal and Italy) is provided under: http://alterfor-project.eu/travellab.html
- ALTERFOR Deliverables: https://alterfor-project.eu/wp4.html
- Deliverable 4.2 – Report on supporting local and national networks for forest management model alternatives
- Jürges, N., Krott, M. (2018). Internationale Waldbauforschung für die Praxis – Professioneller Wissenstransfer durch das RIU Model. Landbauforsch, Appl Agric Forestry Res 3/4 (68): 53-66
- Lodin, I. (2018a). Milestone 18 – 1st Stakeholder Workshop. First Swedish Stakeholder Workshop: Workshop documentation. ALTERFOR project. https://alterfor-pro-ject.eu/files/alterfor/download/Deliverables/Wp4%20report_1st%20stakeholder%20workshop%20sweden.pdf
- Lodin, I. (2018b). Milestone 19 – 2nd Stakeholder Workshop. Second Swedish Stakeholder Workshop: Workshop documentation. ALTERFOR project. https://alterfor-project.eu/files/alterfor/download/Deliverables/2nd_stakeholder_workshop_sweden.pdf
- Marques M., Jürges N., Borges, J. G. (2020). Appraisal framework for actor interest and power analysis in forest management – Insights from Northern Portugal. Forest Policy and Economics 111
- Italy: https://alterfor-project.eu/id-2019-travellab-in-padova.html
- https://alterfor-project.eu/files/alterfor/download/Events/Padova/ALTERFOR_Padova_Travellab_01.pdf
- Ireland: https://alterfor-project.eu/files/alterfor/download/Deliverables/D_5.14_Individualised%20communication%20materials_web.pdf

9. Tailoring your own project for improving the forest by FMMs

If you got interested in the Forest Management Models concept this chapter will show you **how you can make best use of the FMMs in order to improve current management** in the particular forest. If you are a forest owner, you might consider to intensify timber production in some stands or to enhance nature values in other stands. As a state agency you might reconsider the balance of the Ecosystem Services you promote or as a NGO you might push greener thinking in forestry on landscape, regional or national level. Independent of your specific mission one **key rational** of your "project" will be the influence forest management will have on the Ecosystem Services the forest provides. The complex links between forest management and the Ecosystem Services on the stand, regional and national level are the subject of FMMs modelled by ALTERFOR and described shortly in this Road Map. These science-based insights provided by ALTERFOR need to be actively tailored by you in order to best serve demand of your practical project(s).

Basically **three steps** are necessary to apply FMMs. Each step is innovative and needs several, self-critical questions. Before starting with the first step, you however need to be clear whether you are willing to introduce change in your forest management and whether you have sufficient scientific, technical, economic and policy means available to design a project based on FMMs successfully in the forest area you are interested in.

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9.1 STEP 1: Is the FMM relevant for me and the specific forest area?

The (alternative) FMMs are general but the relevance is always specific for their users and so for you, your forest area which might be a stand, a region or national wide forests and the policy and economic background you are acting in.

9.1.1 Relevance with regard to the practical problems and political process

The FMMs address particular types of forests, the Ecosystem Services they provide so as related silvicultural techniques. Primarily, the alternative FMMs show alternatives in producing timber, storing CO2, enhancing biodiversity and recreation services and providing clean water. They steer the output of these Ecosystem Services mainly by elements of harvesting, rotation age, mix of tree species and tending. If the problem is how to **maximize one of the above mentioned Ecosystem Services or to find the optimal balance for a bundle of those Ecosystem Services** then the conclusions based on FMMs might be relevant for you.

As next, look into the silvicultural concept that you apply. If you find a **link** of your silvicultural goals and techniques to those used by the FMMs and simulated Ecosystem Service provision, then current or alternative FMMs might be relevant for you. By analysing this link you might either get strong arguments in support of your silvicultural practice or learn from contradictions with the FMMs.

Take also the time frame into account. ALTERFOR is working with simulation taking 50 or 100 years into account. Is such rather long period important for you? If not, you can either utilise part of the results that from the time perspective suites to your needs or abolish offered FMMs as the option for you.

Finally, have a look to your economic and political environment. Are forest and forest management so as specific Ecosystem Services a **pressing issue** already or can such problems be pushed by you to become an issue for your business or policy? If not, then the time might not be ripe to jump on the key questions to which the FMMs are providing science based insights.

9.1.2 Relevance in regard to allies

Pushing for change in practice of forest management is a highly challenging task. For moving the wide spread "forestry inertia of tradition" you need allies. You might find them within your forest enterprise, among other enterprises, state agencies or organized interest groups with a forestry, economic, nature conservation, climate change or social agenda. If you focus on specific FMMs, silviculture technique or Ecosystem Service you might even be able to build bridges to allies who are (in general) not old friends of you.

In the search for allies be aware of their different types: **(i) Internal allies** will join your project closely and participate more directly when adapting or implementing FMMs; **(ii) External allies** will typically keep distance to specific projects, but they are not less important for pushing implementation because they can put political or economic incentives or even pressure on other actors to join the project or the implementation process. E.g., think about EU programs or programs for regional development, climate change, etc. Finally, there is a slight chance to trigger **(iii) learning allies,** who will first learn from FMMs and then adapt their ideas about silviculture management to it. E.g. nature conservation groups and state agencies might rethink their dead wood strategy if they learn from modelling

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how the damage by fire my increase due to dead dry trees being ladders for fire from the ground to the crown area.

9.1.3 Relevance toward public goals

Enhancing biodiversity, providing raw material for bio-economy or storage of the climate poison CO2 are widely acknowledged public goals. The FMMs are basically linked to these goals. Nevertheless, it is important to check which **strong public goals your specific forestry project will serve**.

It might be worth to jump from general right into thinking of what contribution your project may have to some particular public goals. As a source for ideas, but more importantly as a reference, you should use programs launched by ministries, international processes but also well acknowledged norms of a civil society. Avoid legitimation of your project only by narrow forest goals like sustainable forestry, because of their limited political outreach.

➲ **If your answer to the questions from the Step 1 (about the relevance for your specific mission and project) is one strong YES then go to Step 2!**

9.2 STEP 2: Is the scientific basis of the relevant FMM sound and available?

This step is based on the Step 1 (if the answer was YES) and includes three subsequent considerations.

9.2.1 Cooperation with scientific institutions and projects

For learning from the relevant FFMs or doing more like applying the FMMs to your forest area you need the **direct contact to the scientific team** which has modelled the FMMs.

If you make conclusions about changing forest management or forest policy get in direct contact with the researchers and discuss the strengths and the limits of the scientific basis. Scientific models of FMMs are sound but they have specific uncertainties in data and limits by assumptions. By direct contact the scientists will inform you openly about these presuppositions of the specific models and the fit of the FMMs to you forest area.

9.2.2 Compliance with the procedure of good scientific practice

You have to judge the scientific credibility of the research institution the team is part of and look to some **indicators of scientific quality** like published results in scientific journals or links of the team to other researchers especially research institutions you have close cooperation like national state forest research institutes.

It might be worth doing and it is not unfair to get an additional independent judgment on the scientific quality of the FMMs before you decide and put heavy efforts in implementing the FMMs.

Do not trust and use models that are done by isolated researchers, never published and communicating rather spectacular results. Such scenarios are often cited in media but they do not provide a reliable scientific basis for decisions.

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9.2.3 Selecting and improving scientific scenarios

The results of the check of the scientific quality will not show that one specific FMM fully fits to your problem. Science can neither answer the very specific questions of practice nor provide comprehensive best solutions. But the FMMs inform you about scientifically proven long term effects of silviculture management. You are free to select the information that is relevant for you. You may decide that additional scientific information is needed or that the **selected scientific information is helpful** for you improving forest management and policy. If the information deficits are too big, you may think about initiating additional research projects.

➲ **If you answer step 2 with a strong yes go to Step 3!**

9.3 STEP 3: How to best implement my chosen silvicultural management concept that is based on scientific information by FMMs?

Based on the Steps 1 and 2 you have a good judgement that the FMMs based silviculture management is highly relevant for your problems in the specific forest area and that that the expected outputs of particular Ecosystem Services are scientifically proven. Only now it is worth to start the Step 3, which is a resource consuming, stressful and risky implementation process leading to the changes in your forest.

9.3.1 Embedding in the legal framework

Law is a durable and strong, it restricts and enables forest management on the ground. Therefore, check your legal space of action first. Available regulatory, financial and informational instrument are formulated in your national laws. Use the legal rights which support your forest management, e.g. rights of private ownership or rights to apply for public funding.

But be also well aware of the legal limits. Overcoming them might be a long lasting political process.

9.3.2 Embedding in the economic resources

In forest management practice any silvicultural solution needs sufficient economic resources, either from the market or from the existing funds. Economically efficient acting will save resources and open a broader space of action. Be realistic on economic resources available to you on a long term base for improving the forest and avoid wishful thinking.

9.3.3 Embedding in "good governance"

Of course, improvement of silviculture management is not forever caught within the limits set by law and/or economic resources. By good governance strategies you may enlarge your space of action. Participation of multiple actors in your project might increase many kinds of political and economic support for your project. Consumers of wood products and citizens have a potential to support forest projects, which is seldom activated by forestry. Besides, search for professional support in conducting all your governance efforts, because even if these efforts sound nice they are rather tricky to be accomplished by foresters.

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9.3.4 Embedding in democracy

Be aware that you are doing silviculture management within a democratic environment. This means that you should not change the forest significantly without informing citizens and media. The FMMs might be a highly useful backbone of your PR strategy to communicate the long-term development of the forest to laypersons, who (and often also foresters) can hardly imagine the long term development of the forest right.

9.4 CHECKLIST for successful, tailored, local forest management projects

For a final evaluation, you may use the criteria listed in the Steps 1 to 3 as a kind of a Checklist. Look to the information provided by this road map about the scientific background and the science based results of alternative FMMs. They may guide you to answers of the questions from the checklist (Figure 14). Design your own, specific silviculture management concept that is based on the FMMs but fits to your forest area and your economic and political environment best. Finally, check the solutions by the Steps 1 to 3 again. The more positive answers you can give, the better the odds for your project. Good luck!

Figure 14. Checklist

STEP 1 **Is the FMM relevant for you and the specific forest area?**	• Is there a relevance to practical problems and the political process?	✓
	• Is there a relevance with regard to allies?	✓
	• Is there a relevance toward public goals?	✓
STEP 2 **Is the scientific basis of the relevant FMM sound and available?**	• Is there cooperation with scientific institutions and projects?	✓
	• Is there compliance with the procedure of good scientific practice?	✓
	• Have you selected a scientific scenario?	✓
STEP 3 **How to implement the chosen silvicultural management concept best?**	• Is the chosen silvicultural management concept embedded in the legal framework?	✓
	• Are there sufficient economic resources to implement the chosen silvicultural management concept?	✓
	• Are there good governance strategies?	✓
	• Are you doing silviculture management within a democratic environment?	✓

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10. Suitable research institutions in different case countries

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References

Biber, P., Nieuwenhuis, M., Nordström, E.-M., Black, K., Borga, M., Borges, J.G., Eriksson, L.O., Felton, A., Hengeveld, G., Hoogstra-Klein, M., Lindbladh, M., Zoccatelli, D., (2019). Synthesis report: New forest management models in a landscape perspective: Innovation needs and gains in ecosystem service provisioning. ALTERFOR deliverable D3.4, online at: https://alterfor-project.eu/files/alterfor/download/Deliverables/ALTERFOR%20D3.4%20aFMM%20Synthesis%20Report.pdf

Biber, P., Felton, A., Nieuwenhuis, M., Lindbladh, M., Black, K., Bahyl J., Bingöl, Ö., Borges, J.G., Botequim, B., Bugalho, M., Corradini, G., Eriksson, L.O., Forsell N., Hengeveld, G. M., Hoogstra-Klein, M.A., Kadıoğulları, A.İ., Karahalil, U., Lodin, I., Lundholm, A., Makrickienė, E., Masiero, M., Mozgeris, G., Pivoriūnas, N., Poschenrieder, W., Pretzsch, H., Sedmak, R., Tucek, J., (2020). Forest Biodiversity, Carbon Sequestration, and Wood Production: Modelling Synergies and Trade-Offs for Ten Forest Landscapes across Europe, Frontiers Ecology and Evolution, Submitted Paper.

Blattert, C., Lemm, R., Thees, O., Lexer, M.J., Hanewinkel, M., (2017). Management of ecosystem services in mountain forests: Review of indicators and value functions for model based multi-criteria decision analysis. Ecological Indicators 79, 391–409. https://doi.org/10.1016/j.ecolind.2017.04.025

Borges, J. G., Marques, S., Garcia-Gonzalo, J., Rahman, A. U., Bushenkov, V.A., Sottomayor, M., Carvalho, P. O., Nordström, E.-M. (2017). A multiple criteria approach for negotiating ecosystem services supply targets and forest owners' programs. Forest Science 63: 49–61. https://doi.org/10.5849/FS-2016-035

Dunker, P.S., Barreiro, S.M., Hengeveld, G.T., Lind, T., Mason, W.L., Ambrocy, S., Spiecker, H., (2012). Classification of Forest Management Approaches: A New Conceptual Framework and its Application to European Forestry. Ecology and Society 17(4) 51.

Forsell, N.; Korosuo, A. (2016) Milestone 6–Global and Country Specific Prospective Scenarios. ALTERFOR. https://alterforproject.eu/files/alterfor/download/Deliverables/MS%206%20Global%20and%20country%20specific%20scenarios_1.pdf

Ferreira, L., Constantino, M., Borges, J. G., Garcia-Gonzalo, J. (2015). Addressing wildfire risk in a landscape level scheduling model. An application in Portugal. Forest Science 61: 266-277. https://doi.org/10.5849/forsci.13-104

Hengeveld, G.M., Nabuurs, G.j., Didion, M., vdn den Wyngaert, I., Clercx, A.P.P.M., Schelhaas, M.J., (2012). A forest management Map of European Forests. Ecology and Society 17(4) 53.

Jürges, N., Krott, M. (2018). Internationale Waldbauforschung für die Praxis – Professioneller Wissenstransfer durch das RIU Model. Landbauforsch, Appl Agric Forestry Res 3/4 (68): 53-66.

Krott, M. (2005). Forest Policy Analysis. Springer.

Krott, M. (2008) Forest government and forest governance within a Europe in change. In: Cesaro, Gatto, Petenela (eds.) The Multifunctional Role of Forests – Policies, Methods and Case Studies, EFI Proceedings 55: 13-26.

Lodin, I.; Eriksson, L.O.; Forsell, N.; Korosuo, A. Combining Climate Change Mitigation Scenarios with Current Forest Owner Behavior: A Scenario Study from a Region in Southern Sweden. Forests 2020, 11, 346.

Lodin, I. (2018a). Milestone 18 – 1st Stakeholder Workshop. First Swedish Stakeholder Workshop: Workshop documentation. ALTERFOR project. https://alterfor-pro-ject.eu/files/alterfor/download/Deliverables/Wp4%20report_1st%20stakeholder%20workshop%20sweden.pdf

Lodin, I. (2018b). Milestone 19 – 2nd Stakeholder Workshop. Second Swedish Stakeholder Work-shop: Workshop documentation. ALTERFOR project. https://alterfor-project.eu/files/alterfor/download/Deliverables/2nd_stakeholder_workshop_sweden.pdf

Lundholm et al. (2020): Evaluating the impact of future global climate change and bioeconomy scenarios on ecosystem services using a strategic forest management decision support system.

Lundholm et al. (2019). Implementing Climate Change and Associated Future Timber Price Trends in a Decision Support System Designed for Irish Forest Management and Applied to Ireland's Western Peatland Forests; https://www.mdpi.com/1999-4907/10/3/270

Lundmark, T., Bergh, J., Nordin, A., Fahlvik, N., Poudel, B.C., (2016). Comparison of carbon balances between continuous-cover and clear-cut forestry in Sweden. Ambio 45, 203–213. https://doi.org/10.1007/s13280-015-0756-3

Marques M., Juerges N., Borges, J. G. (2020). Appraisal framework for actor interest and power analysis in forest management – Insights from Northern Portugal. Forest Policy and Economics 111. https://doi.org/10.1016/j.forpol.2019.102049

Marto, M., Reynolds, K. M., Borges, J. G., Bushenkov, V. A., Marques, S., Marques, M., Barreiro, S., Botequim, B., Tomé, M. (2019). Web-Based Forest Resources Management Decision Support System. Forests 10, 1079. https://doi.org/10.3390/f10121079

Matthews, J. D., (1989). Silviculture systems. Oxford University Press., 284p

Feliciano, D., Blagojević, D., et al. (2019). Learning about forest ownership and management issues in Europe while travelling: The Travellab approach. Forest policy and economics, 99, pp.32-42.

Oliver, C.D., Nassar, N.T., Lippke, B.R., McCarter, J.B., (2014). Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests. Journal of Sustainable Forestry 33, 248–275. https://doi.org/10.1080/10549811.2013.839386

Schwaiger, F., Poschenrieder, W., Biber, P., Pretzsch, H., (2019). Ecosystem service trade-offs for adaptive forest management. Ecosys.Ser. 39, 100993. https://doi.org/10.1016/j.ecoser.2019.100993

Subramanian, N.; Nilsson, U.; Mossberg, M.; Bergh, J. Impacts of climate change, weather extremes and alternative strategies in managed forests. Écoscience 2019, 26, 53–70, https://www.tandfonline.com/doi/pdf/10.1080/11956860.2018.1515597

Vilén, T., Fernandes, P.M., (2011). Forest Fires in Mediterranean Countries: CO2 Emissions and Mitigation Possibilities Through Prescribed Burning. Environmental Management 48, 558–567. https://doi.org/10.1007/s00267-011-9681-9

Zadeh, L.A., (1965). Fuzzy sets. Information and Control 8, 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

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