ALTERFOR

Deliverable 3.4 – Synthesis report: New FMMs in a landscape perspective: Innovation needs and gains in ES provisioning

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Abbreviations used

aFMM – Alternative forest management model
CCF – Continuous cover forestry
cFMM – Current forest management model
CSA – Case study area
DSS – Decision support system
ES – Ecosystem service
FMM – Forest management model
GHG – Greenhouse gases
HWP – Harvested wood products
LCC – Local case study coordinator
PA – Project Administrator
PC – Principle component
PCA – Principle component analysis
PCo – Project Coordinator
SC – Scientific Coordinator
WP – Work Package
WPLs – Work Package Leader(s)

1 Introduction

This document is the ALTERFOR deliverable D3.4, which gives a synthesis of the projected provision of key ecosystem services (ES) under new, alternative forest management models (aFMM) in all case study areas (CSAs) of the project. This report has to be seen in combination with deliverable D3.2 (ALTERFOR WP3 Leaders, 2018c), the synthesis of ES provision under current forest management models (cFMM). In a similar way as milestone MS11 (ALTERFOR WP3 Leaders, 2018a) was the basis for D3.2, this report is based on milestone MS12 (ALTERFOR WP3 Leaders, 2018b). To facilitate ease of access and comparison, the structure of D3.4 and D3.2 is very similar. We have to mention, however, that comparisons of D3.2 and D3.4 results have to be done with a grain of salt. Since the scenario runs for the cFMMs, the DSSs and simulation models used in ALTERFOR have been further developed, especially in their possibilities to account for climate change effects and timber price scenarios.

The work in ALTERFOR is based on CSAs in nine European countries (from North to South: Sweden, Lithuania, Ireland, Netherlands, Germany, Slovakia, Italy, Portugal, Turkey). Except Germany, which hosts two CSAs, there is one CSA per country, resulting in a total of ten CSAs (Figure 1 and Table 1). These CSAs are forest landscapes covering sizes between several thousands and several hundred thousands of hectares. They were selected as being representative for important problems at the interface of forest management and forest policy. Usually, the case studies' significance is not restricted to the country they are located in but extends to comparable situations in their whole respective climate zone. E.g. the Irish case study can serve as an example for vast peatland areas throughout the Northern part of Europe.

In ALTERFOR each country used its own decision support system (DSS) /forest simulation model. On the one hand, this has the advantage that the projections were done with the best possible applicability for the specific CSA conditions. On the other hand, this 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 climate and timber demand scenarios could not be incorporated in the same way and to the same extent in all case studies (for details see ALTERFOR WP3 Leaders, 2018a, b). In brief, the three global frame scenarios are (summarised from ALTERFOR WP2 Leaders, 2016):

- Reference scenario – Future pathways based on historical development. Taking into ac-count the EU policies and targets until 2020 that are in the current legislation, thereafter continuing with some development towards the climate targets, following the typical pathways experienced in the past. The global economic growth and population development are expected to be consistent with typical pathways experienced in the past. The climate change is slightly halted through additional policies on greenhouse gas emission mitigation and some development of carbon capture technologies. The global temperature will be about 3.7 degrees Celsius higher by 2100 than the pre-industrial level.
- EU Bioenergy scenario – Rapid development of the EU bioenergy sector. Taking into ac-count EU policies that aim at an 80% reduction in emissions by 2050, with some global cli-mate policies in place. In this scenario, the emission reduction targets in the EU for 2030 and 2050 are assumed to be fulfilled. The biomass demand for energy is assumed to re-main stable

thereafter in the EU. Instead, the importance of woody biomass as a feed-stock for material production is increasing. Outside the EU, it is assumed that additional climate change mitigation policies are in effect, so that the global temperature will be ca. 2.5 degrees Celsius higher by 2100 than the pre-industrial level.

- Global Bioenergy scenario – Global development toward the climate targets. Climate policies are assumed to be taken into action globally, with both stringent EU policies and strong global climate mitigation. In the EU, the same targets until 2050 are in place as in the EU BIOENERGY scenario. Additionally, strong global mitigation actions are expected to be taken in all sectors and the bioenergy demand is expected to increase through the in-vestments in CHP (combined heat and power) as well as of carbon capture technologies. The climate policy is strict and together with alternative energy sources and strong development of carbon capture technologies leads to reaching the climate targets of global temperature increase, resulting in a temperature increase of 1.5 to 2.0 degrees Celsius by 2100, compared to pre-industrial level.

Thus, the scenarios represent different climate change and bioenergy/wood demand developments, which may impact on forest productivity, disturbances, timber production and utilisation.

In order to partly overcome methodological differences resulting from applying different projection tools and different ways of incorporating the global frame scenarios, ALTERFOR at an early stage defined a standard set of output variables as a common requirement to be provided by all case studies (Nordström et al., 2019).

The ALTERFOR Milestone 12, projections with alternative forest management models (aFMM) per CSA, was completed on December 21, 2018 (ALTERFOR WP3 Leaders, 2018b). It consists of a compilation of DSS results for aFMMs under the three global frame scenarios - Reference, EU Bioenergy and Global Bioenergy. The next stage consisted of the local case study coordinators (LCCs) producing assessments of the six ESs included in ALTERFOR (biodiversity conservation, timber production, carbon sequestration, regulatory services, cultural services and water-related services) and timber for their CSAs. The LCCs were facilitated in this by example ES assessments from the ALTERFOR Ecosystem Service (ES) Expert Group. The ES assessments produced by the LCCs were then sent to the ES Experts, who produced synthesis reports for all ESs, bringing together the most important results and trends from the CSA reports.

This document consists of three main parts (introduction not counted). The first part (Chapter 2) provides a cross-country overview of selected important DSS output variables and their projected development under the simulated aFMMs over 100 years. This part is intended to allow readers to get familiar with the basic information which was used by the LCCs and ES experts for producing their assessments. These assessments are presented in the second part (Chapter 3) to the full extent. In the third part (Chapter 4), we come to a synthesis about the potential and limits to steer ES provision with alternative forest management models.

Figure 1 Map showing the countries with ALTERFOR case studies.

Table 1 Details of the case study areas (CSAs) used in the ALTERFOR project

(Country code) Name(s)	Area, 1000 ha (% forest)	Forest ownership (%)	Main stakeholders	Main ES	Available DSS(s)
(SWE) Kronoberg county	847 (77)	83 Private 17 Public	FOA[1], ENGO[2], forest industry, Swedish Forest Agency, public	Timber, Biodiversity, Water, Recreation	Heureka HoSim
(LTU) Telšiai	254 (34)	63 Private 37 Public	Institute of Forest Management Planning, state forest managers, PFO[3], ENGO, regional park	Timber, Biodiversity Water, Recreation	Kupolis
(SVK) Podpolanie	34 (57)	7 Private 93 Public	State forest managers, PFO, ENGO, general public	Timber, Biodiversity Water, Recreation	Sibyla
(IRL) Barony of Moycullen	81 (16)	22 Private 78 Public	Forest service, advisory services, PFO, ENGO, industries, public, fisheries, investment bodies	Timber, Biodiversity Water, Recreation	Growfor Remsoft
(ITA) Veneto	76 (100)	74 Private 26 Public	PFO, logging enterprises, municipalities, regional forest administration, ENGO	Timber, Biodiversity Water, Erosion control	InVEST RockyFO CO2Fix
(PRT) Sousa Valley	15 (10)	100 Private 0 Public	FOA, forest owner federation, forest industry, forest service, local municipality, other NGO	Timber, Recreation	StandSim SADfLOR
(DEU) Augsburg Western Forests (AWF)	150 (33)	50 Private 50 Public	PFO, ENGOs, forest service, forest industry, general public (stable ownership structure for decades)	Timber, Biodiversity, Recreation, Water, Soil protection	SILVA
(DEU) Lieberose - Schlaubetal (LS)	90 (37)	44 Private 56 Public	PFO (their share steadily increasing), forest service, ENGOs, forest industry, general public	Timber, Biodiversity, Recreation, Soil protection	SILVA
(NLD) Netherlands	3,734 (11)	52 Private 48 Public	Government: National, Regional & Owners: Owner association, State forestry, National Trust, NIPF & General public	Timber, recreation, biodiversity	EFISCEN-space
(TUR) Turkey	81 (49)	91 Public 9 Private	Gölcük state forest enterprise, timber processing companies, nature protection agency, forest cooperatives and contractors, forest villagers	Timber, biodiversity, soil conservation, recreation, water	ETFOP

2 Cross Country DSS Result Comparison

For interpreting the alternative forest management models' (aFMM) results it is important to note that these are not uniformly defined across the CSAs. Rather, each CSA defined their own aFMM or several aFMMs based on what concepts turned out to be serious alternatives for important local stakeholders. Table 2 gives a case study wise overview of the aFMMs. Note that if an aFMM was applied for 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.

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Table 2 Overview of the aFMMs applied in ALTERFOR. These concepts have been described in more detail in the MS12 document (ALTERFOR WP3 Leaders, 2018b)

Country	aFMM Name	Concept	Used with global frame scenarios
Sweden	Global Bioenergy	High wood production. Better regenerations and more pre-commercial thinnings, more Scots pine, Hybrid larch, fertilization, Norway spruce clones	Global Bioenergy
	EU Bioenergy	More diverse forest management. More Scots pine, oak for wood production, include border zones without management, spruce-birch ad-mixtures, continuous cover forestry	EU Bioenergy
	Reference	More diverse forest management. More Scots pine, more oak for wood production, more spruce-birch admixtures (compared to EU Bioen-ergy), include border zones without management, Douglas fir, continuous cover forestry	Reference
Lithuania	Adaptive rotation ages	Maximize forest rent	All
	Care for deciduous	Adjust silvicultural priorities towards deciduous species, while conifers still remain important	All
Ireland	Environmentally constrained profit maximisation	Increase profit of blanket peat forests while having low environmental impact. Low stocked planting of lodgepole pine, create good conditions for native broadleaf species, Sitka spruce under birch nurse, bog restoration	All
Netherlands	Reference gfdl	Slightly adapted management based on current developments (gfdl 8.5 climate)	Reference
	Reference hdgem	Slightly adapted management based on current developments (hadgem 8.5 climate)	Reference
	Wood	Focus on timber production (hadgem 4.5 climate)	EU Bioenergy
	Bioenergy gfdl	Focus on local sustainability and bioenergy (gfdl 2.6 climate)	Global Bioenergy
	Bioenergy hdgem	Focus on local sustainability and bioenergy (hadgem 2.6 climate)	Global Bioenergy
Germany (both case studies)	Multifunctional forest	Establish and maintain (uneven-aged) mixed stands in order to provide a broad range of ESs	All
	Production Forest	Maximize wood production with monospecific even-aged conifer forests, reduce share of other forest types	All
	Nature Conservation Forest	Landscape is treated as a strictly protected area; no active silviculture	All
Slovakia	Restitution of ownership	Commercial stands, more planning flexibility	All
	Biodiversity	Increase natural regeneration	All
	Biodiversity & Restitution	Combine both approaches	All
Italy	Recreation & habitat selectivity	Close to nature, improve recreational and cultural forest functions, maintain biodiversity	All
	Uniform shelterwood and coppice	Uniform shelterwood in oak-hornbeam forests, transform coastal forests into holm oak coppice with standards	All
Portugal	Combination of low intensity pine management, broadleaf & sawlog, cork oak and riparian aFMMs	Address problems connected to the perception of eucalypt plantations, fire risk, fragmented ownership, lack of management; develop a landscape mosaic that provides hardwood supply combined with cultural services and biodiversity	Reference[1], EU Bioenergy[1]
Turkey	Continuous Cover Forestry	Provide a multitude of ESs by creating and maintaining uneven aged mixed stands	All

[1] These are local scenarios – Global Bioenergy is not considered due to lack of data, instead there is a Business as usual scenario with no climate change.

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For the comparison of raw results in this chapter, we used so-called spider diagrams in almost the same way as we did in the ALTERFOR deliverable D3.2 for the current forest management models (cFMM). These diagrams are all based on the same layout (Figure 2) which provides a separate axis for each CSA along which the variable of interest is plotted. The axis directions roughly mirror the North-West/East-South order of the case studies.

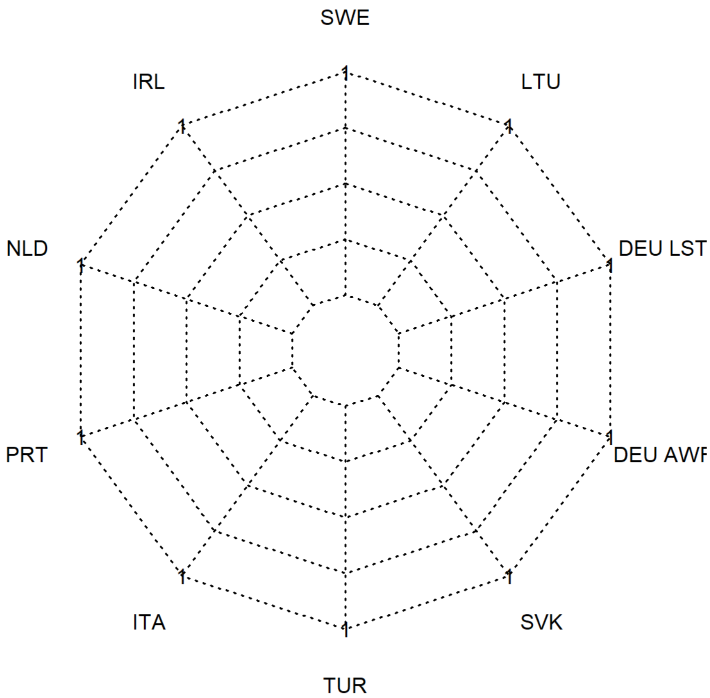

Figure 2 Generic spider diagram layout for the result presentation. Clockwise from the top: Sweden, Lithuania, Germany Lieber-ose-Schlaubetal, Germany Augsburg Western Forests, Slovakia, Turkey, Italy, Portugal, the Netherlands and Ireland.

In contrast to D3.2, it had to be taken into account, however, that some case studies reported more than one aFMM per frame scenario. In such cases, the spider diagrams display two values, the maximum and the minimum obtained in any aFMM. This allows to see the scope of effect achievable by choosing different aFMMs.

As the direct DSS output variables may relate to more than one ES each, we grouped their presentation into three sections: a) Classic Forestry Information, b) Structure and Diversity, and c) Carbon Sequestration related information. E.g. group 'a' does not only provide information about timber production, but also about regulatory services, and water protection. Similarly, group 'b' relates to biodiversity, but typically also to cultural services and water protection, etc. The information presented here is a condensed view on selected variables. The full detailed information this was drawn from and on which the ES experts based their assessments is available on request with the ALTERFOR internal MS 12 document (ALTERFOR WP3 Leaders, 2018b).

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2.1 Classic Forestry Information

As for almost each variable of interest, the results obtained for standing volume (Figure 3) do not differ strongly among the global frame scenarios (Reference, EU Bioenergy, Global Bioenergy). There is, however a general tendency to an increase of the standing volumes during the simulation time span. In the beginning, standing volumes are almost everywhere below 300 m³/ha (lowest in Portugal and Italy), while most case studies got closer to this value or even higher until 2100. For the Netherlands, all runs end between 600 and 900 m³/ha, while there is a noticeable spread between the global frame scenarios in both German case studies. There are management scenarios which keep the standing volume at about the initial level, but the non-management aFMM (nature protection forest) lead to extreme volume accumulations.

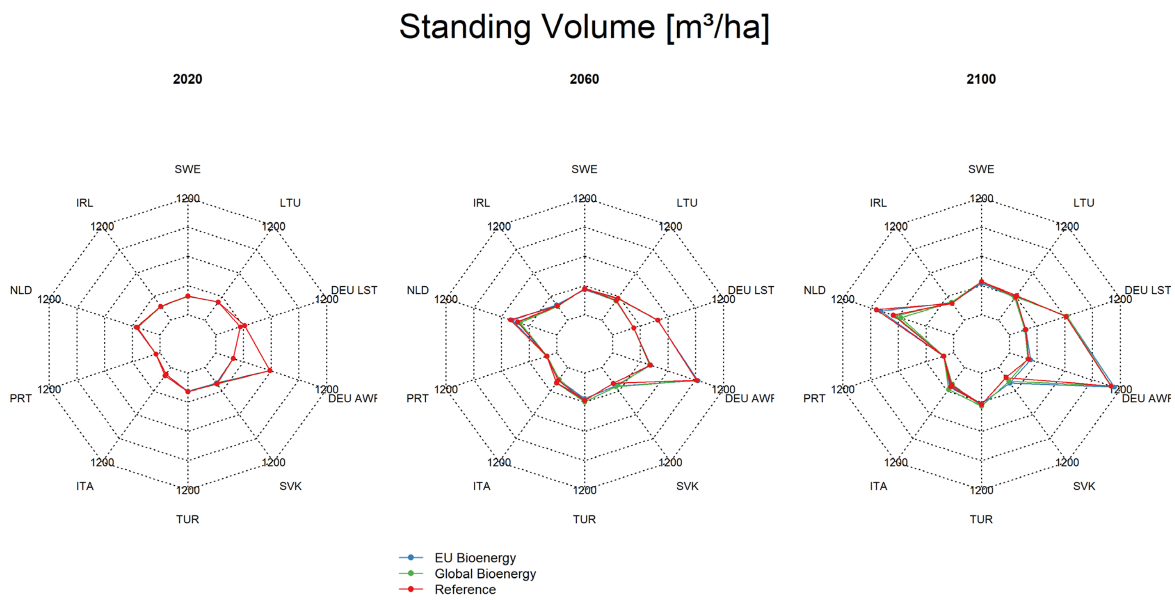

Figure 3 Standing Volume (m³/ha) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

For volume increment (Figure 4) there is also a general tendency towards a (slight) increase or at least stability on the long run. Exceptions are Ireland (strong decrease) and Italy. While in Germany there is an interim differentiation among the aFMM, a consistent differentiation between frame scenarios and aFMMs develops in the Netherlands CSA. Here, the Reference scenario takes the lead, while Global Bioenergy tends towards the lowest increments.

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Volume Increment [m³/ha/year]

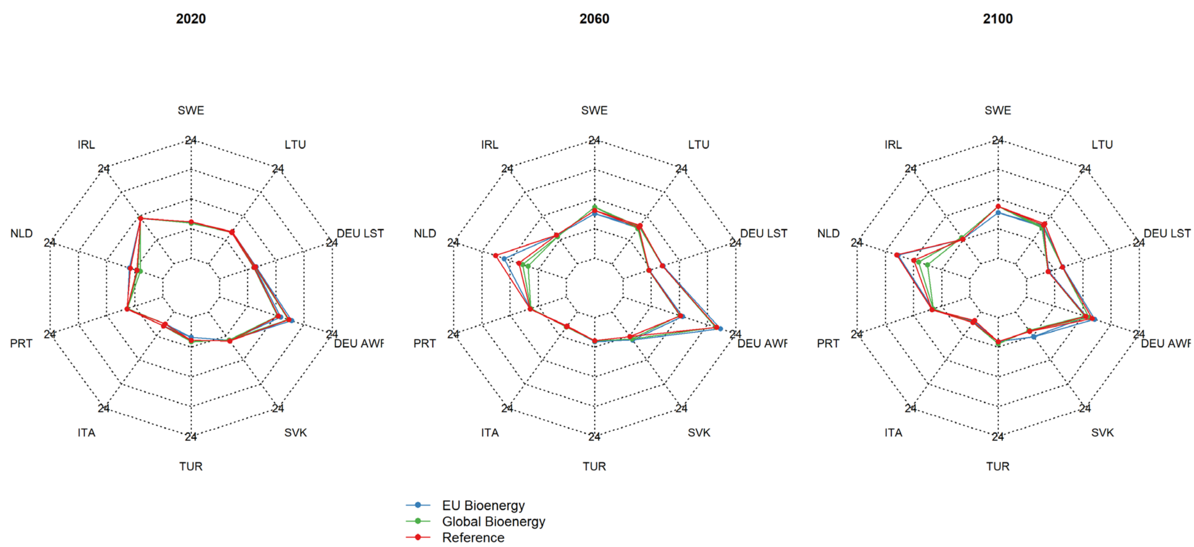

Figure 4 Volume increment (m³/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

The generally increasing standing volumes imply that the amounts of harvested wood (Figure 5) must be – at least initially – smaller than the volume increments. This is true for almost every CSA. Considerable aFMM variation is evident in Italy, Germany LST, and extreme in Germany AWF. The initially extreme harvest amounts in Germany AWF come from the "Production Forest" aFMM which in the beginning harvests all timber considered "over-mature" in this concept. The second peak in 2100 indicates the harvesting wave in the second generation established during the first harvest wave. Germany also consistently shows the lowest harvest amounts due to the zero harvest in the "Nature Conservation Forest" aFMM. A frame scenario-wise differentiation is visible for Ireland, the Netherlands, Sweden, and Slovakia. In these cases, highest harvest volumes are evident in the Global Bioenergy (and EU Bioenergy, Slovakia) scenario and lowest in the Reference scenario, which is in tune with the frame scenarios' assumptions for wood demand.

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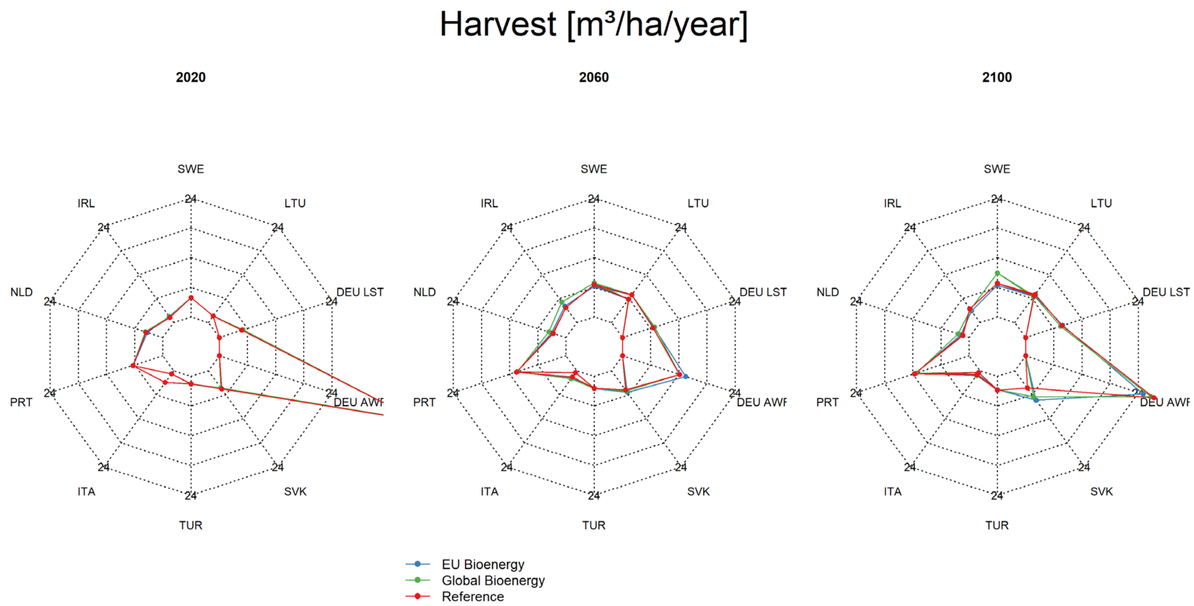

Figure 5 Harvest amount (m³/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

The volume of harvested sawlog (Figure 6) shows virtually the same tendencies, extremes, and scenario differentiations as does harvest in total. This is less the case for the harvested pulpwood (Figure 7). A comparison of sawlog and pulpwood volumes show typical different goal assortments. While sawlogs dominate in the harvest volume in the German CSAs, the picture is balanced in Sweden and Slovakia, while pulpwood strongly dominates in Portugal.

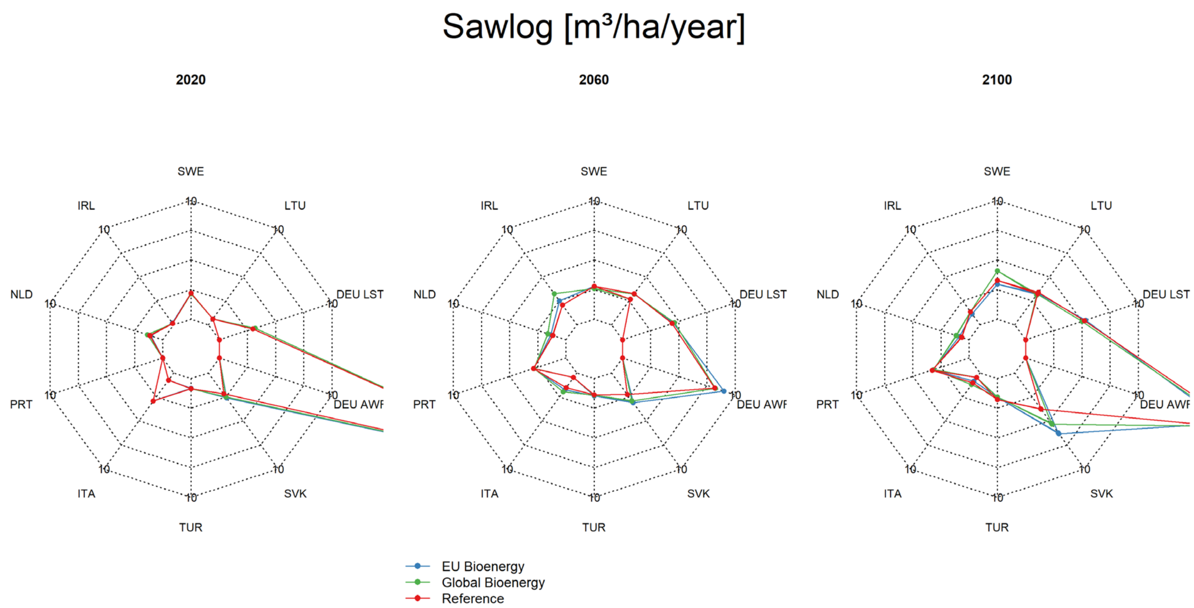

Figure 6 Harvested sawlog volume (m³/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

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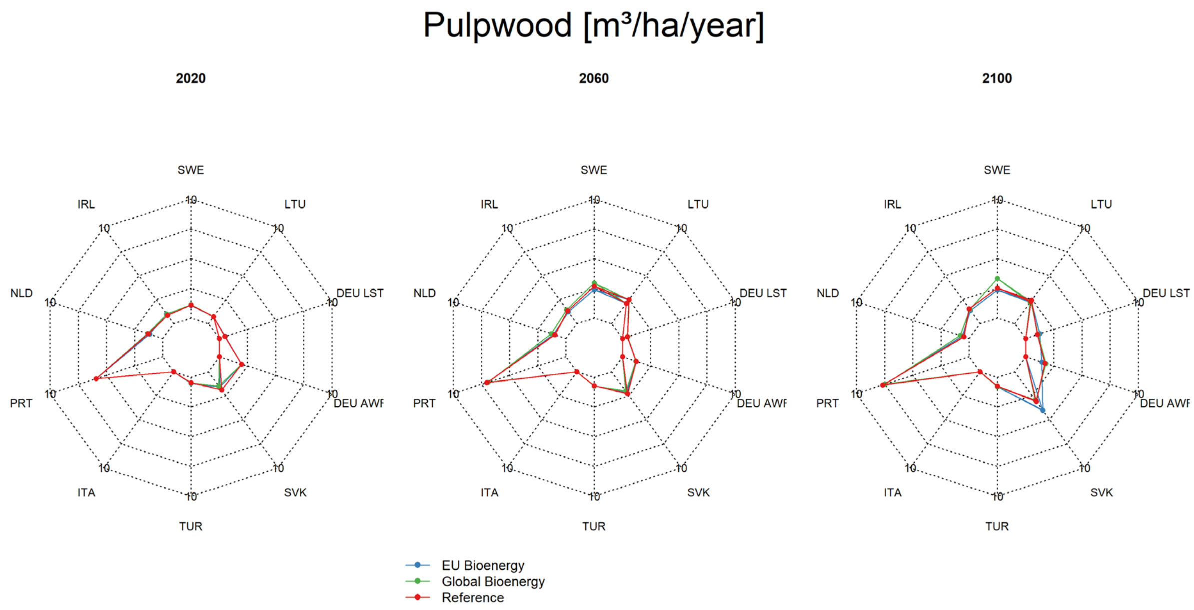

Figure 7 Harvested pulpwood volume (m³/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

2.2 Structure and Diversity

The number of tree species in a CSA (Figure 8) is a useful information by itself, it could, however, 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 to a considerable extent due to a more detailed species registration. It might be also not independent from the CSA size, e.g. the Dutch CSA being the whole Netherlands with 3.7 million ha, and the Portuguese CSA having 15,000 ha only (Table 1). As can be clearly seen from Figure 8, the final numbers of species do not or at almost not deviate from their initial values. Slight species losses seem to occur in Slovakia and Lithuania. Increases of species numbers in the beginning of the simulations are evident for part of the Portuguese and to a lesser extent the Italian aFMMs.

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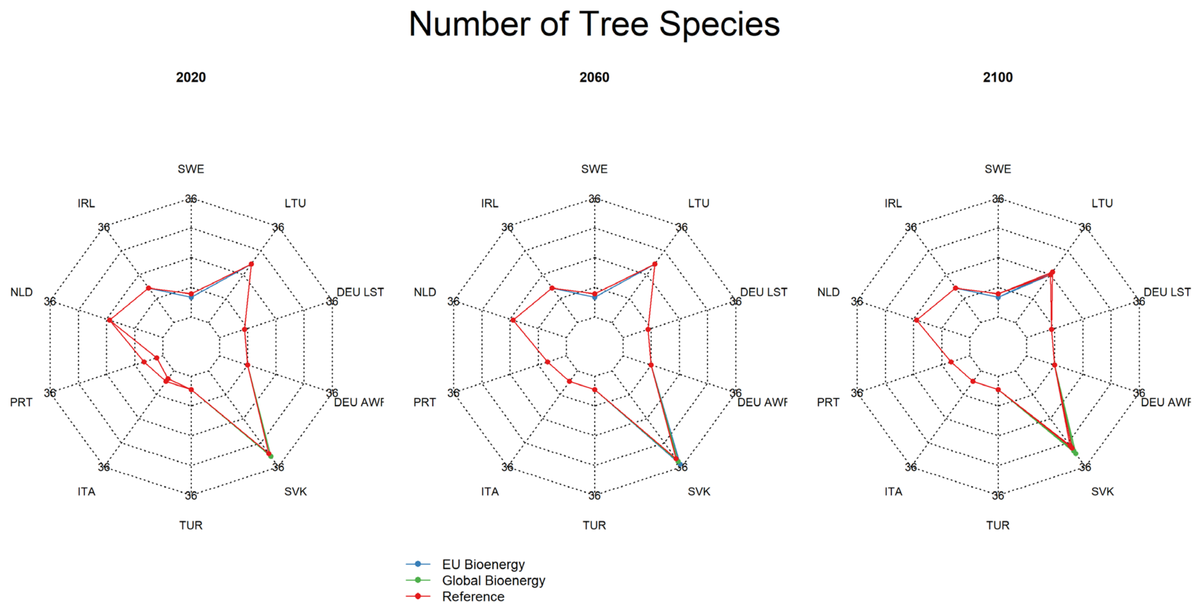

Figure 8 Number of tree species projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

A more informative quantity than the mere number of tree species is the Shannon Diversity Index *H*:

$$H = -\sum_{i=1}^{n} p_i \cdot \ln(p_i)$$

We used it to express diversity on CSA level, thus *n* being the number of species, and based on the species volume shares p_i. Thus, *H* is the higher the more tree species are there, and the more balanced the species' volume shares are. Using volume shares ensures that the occurrence of species added or established on additional areas, which may be numerous in individuals but negligible in biomass is not overrated. An overview of the outcomes for the Shannon Index can be taken from Figure 9.

Consistently the highest values are obtained for the Netherlands, on the long run lowest for Germany LST in one aFMM, Ireland, partly Portugal and Italy. Considerable differentiation among aFMMs becomes visible for Portugal, Italy, and both German case studies. A clear differentiation due to the global frame scenarios is evident for Sweden. Here the Reference scenario ends up with a higher Shannon Diversity than Global Bioenergy and EU Bioenergy. The general development tendency seems to be stability or slight increase of the Shannon Diversity during the simulation time span. Losses are evident for one aFMM in both German case studies, while in the same CSAs also significant increases occur. This indicates considerable steering potential with regard to tree species diversity.

However, while the Shannon index reduces the potential reporting bias of the species numbers, this bias is not eliminated. In order to achieve this as far as possible, the Evenness was calculated (Figure 10).

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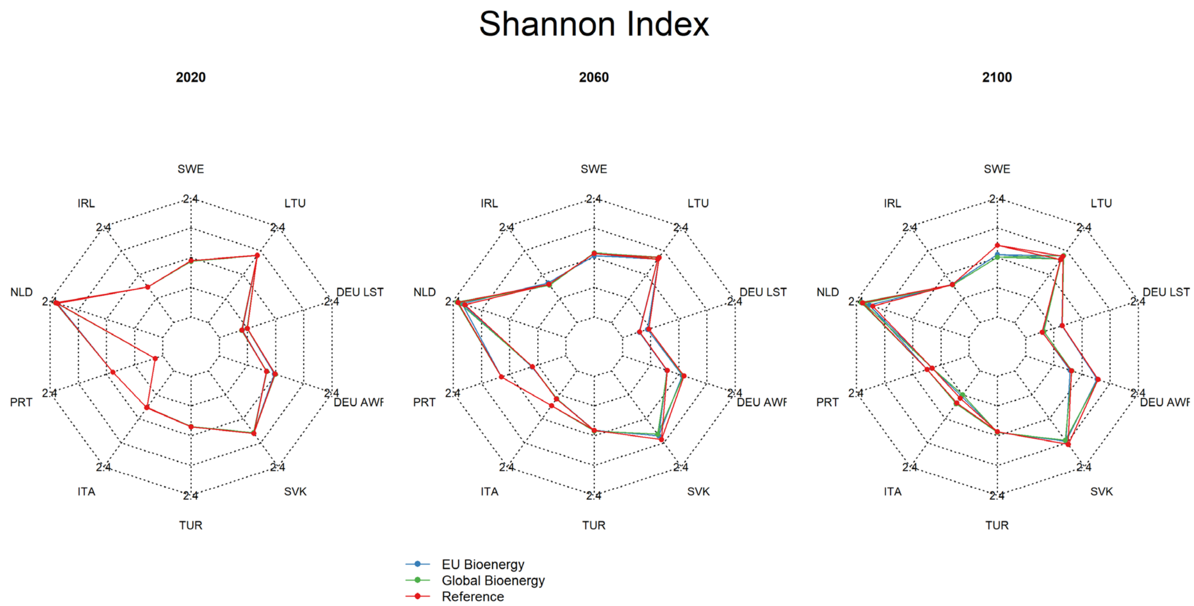

Figure 9 Shannon Diversity Index projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

The Evenness indicator E is the ratio of the actual Shannon Index H and its theoretical maximum which can be easily calculated from the theoretical maximum number n_{max} of tree species in the region of interest as $H_{max} = \ln(n_{max})$. Thus, the Evenness indicator results from:

$$E = -\frac{\sum_{i=1}^{n} p_i \cdot \ln(p_i)}{\ln(n_{max})}$$

Due this concept, the Evenness indicator makes Shannon values from different regions with different natural species abundance comparable. For each CSA, we took the greatest number of species obtained in any scenario and used it as a proxy of n_{max}. Evenness values of 1 would then express maximum tree species diversity (for a certain maximum number of species).

As Figure 10 shows, the Evenness indicator is much more balanced among the case studies than is the Shannon Index (Figure 9). The general tendency towards a slight increase (apart from some exceptions) is the same as for the Shannon Index, but the Evenness indicator does not display as much contrast between the case studies. Most case studies stabilize at Evenness values between 50 and 75% of the maximum diversity, with the highest values in the long run in Sweden, Germany AWF (for one aFMM), Turkey and the Netherlands, and the lowest in Germany LST (for one aFMM).

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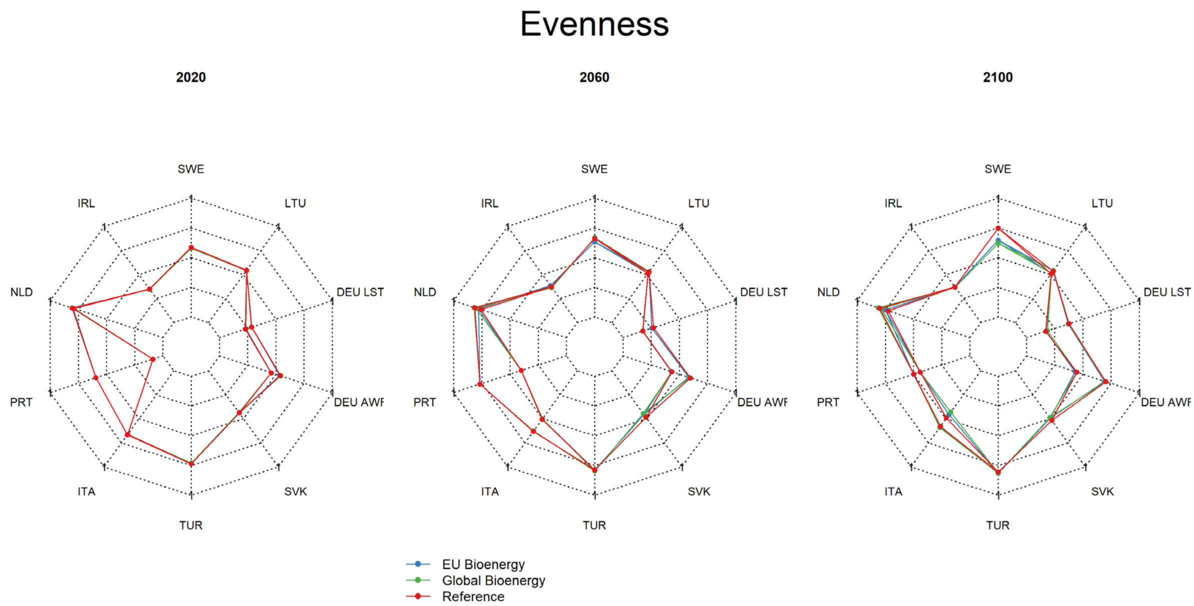

Figure 10 Evenness (0, …, 1) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bio-energy, Reference), shown for the years 2020, 2060, and 2100.

The volume share of broadleaved species (Figure 11) is in many countries, especially those with a long-term tradition of intensive forest management, taken as a measure for the success of forest transformation efforts from conifer plantations towards more site adapted forest types. When comparing this variable across the ALTERFOR case studies, it has to be taken into account, that the share of broadleaves does not only mirror local forest history, but also site conditions. This is evident from Figure 11, where intermediate to high broadleaf shares are visible for the Netherlands, Portugal, Italy, Turkey and Slovakia, and low ones in Sweden and Lithuania. Site suitability and forest management history are probably the most important reasons for the low shares in Ireland and Germany. Remarkably, except for Sweden and partly Slovakia, there is no differentiation among the global frame scenarios. In both countries however, the more demand-driven (and thus production oriented) EU Bioenergy and Global Bioenergy scenarios tend to come with lower broadleaf shares. In the Netherlands and Lithuania there is a slight differentiation among aFMMs, and a strong one in both German case studies, the latter indicating a considerable steering potential between active production management and a reduction of deciduous tree species.

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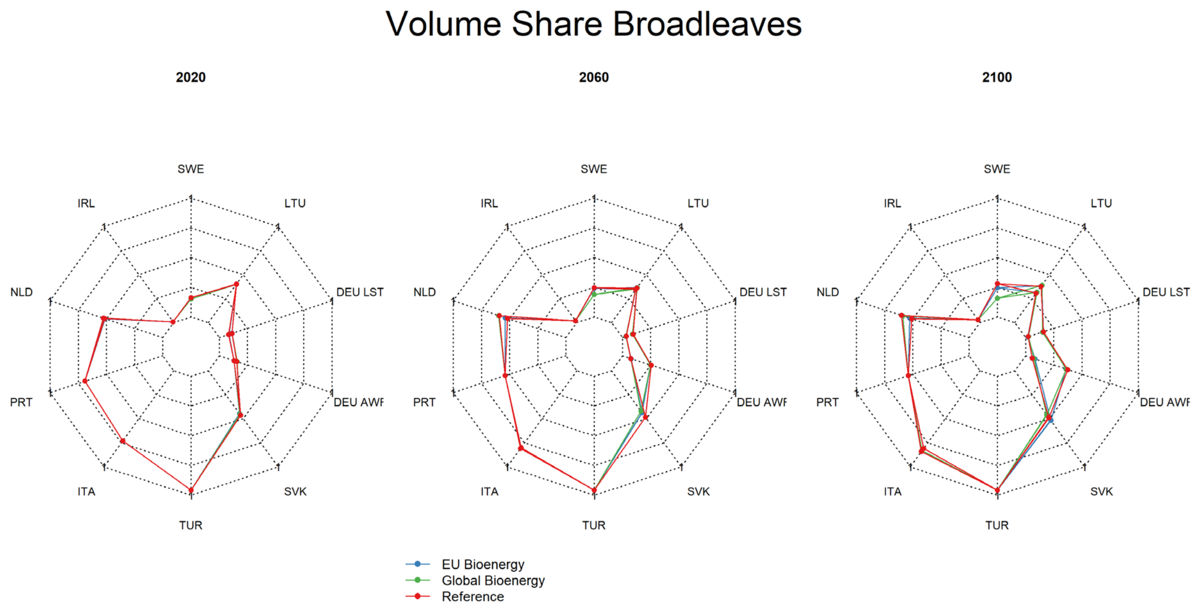

Figure 11 Standing volume share of broadleaved tree species (0, …, 1) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

Similar to the volume share of broadleaved species (Figure 11), the share of areas with understory does reflect management history as well as site conditions, but probably also different understory definitions among the countries (e.g. probably the understory definition in Germany is more tolerant compared to Slovakia). Nevertheless, the tendencies are interesting (Figure 12). Understory coverage is and remains at maximum in the Netherlands, Portugal, Turkey. In Germany, it starts high and keeps a high level, albeit with a slight up- or downwards trend, depending on the aFMM. In Italy, we observe a reduction from high to intermediate values; a slight reduction at low levels is visible for Lithuania and Slovakia. In Sweden there is a slight fluctuation at low values with the Reference global frame scenario switching rank with the other two frame scenarios.

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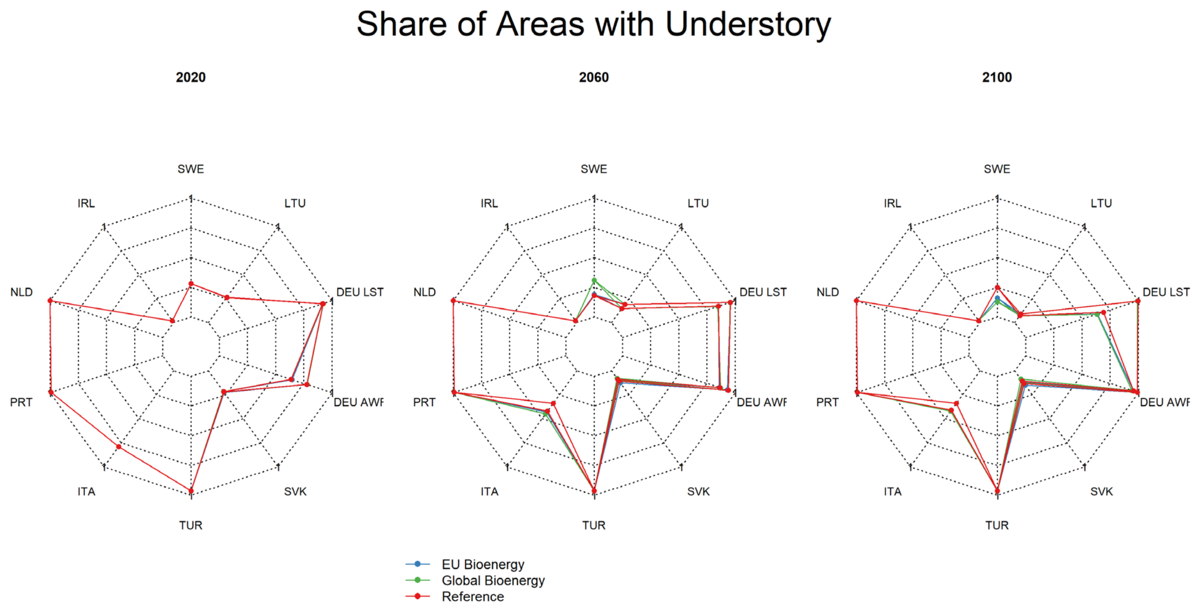

Figure 12 Share of forest areas with understory (0, …, 1) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

The volume per unit area made up by large trees is a standard indicator for forest diversity as such trees provide, due to their more complex structure and longer lifetime, more and more diverse niches for other plants and also animals. Figure 13, in this context, shows the volume of the trees with a diameter at breast height of more than 40 cm. This variable is not available for Italy, but for all other countries it is evident that initially the values are about 100 m^3/ha or below. Except for the Netherlands and Germany, there is an overall tendency towards a slight increase. In Sweden, we observe a slight frame scenario differentiation, with Reference ending up highest. In the Netherlands, the volume of large trees shows an enormous increase, which is only overrun by the Nature Protection Forest aFMM in the German AWF region, as a result of no harvest during 100 years. A strong but less pronounced increase due to less favourable site conditions results for the same aFMM in the German LST CSA. Again, the aFMM-wise scenario differences in Germany are extreme; the other extreme is the large tree volume which is almost constant (AWF) or decreasing to close to zero (LST).

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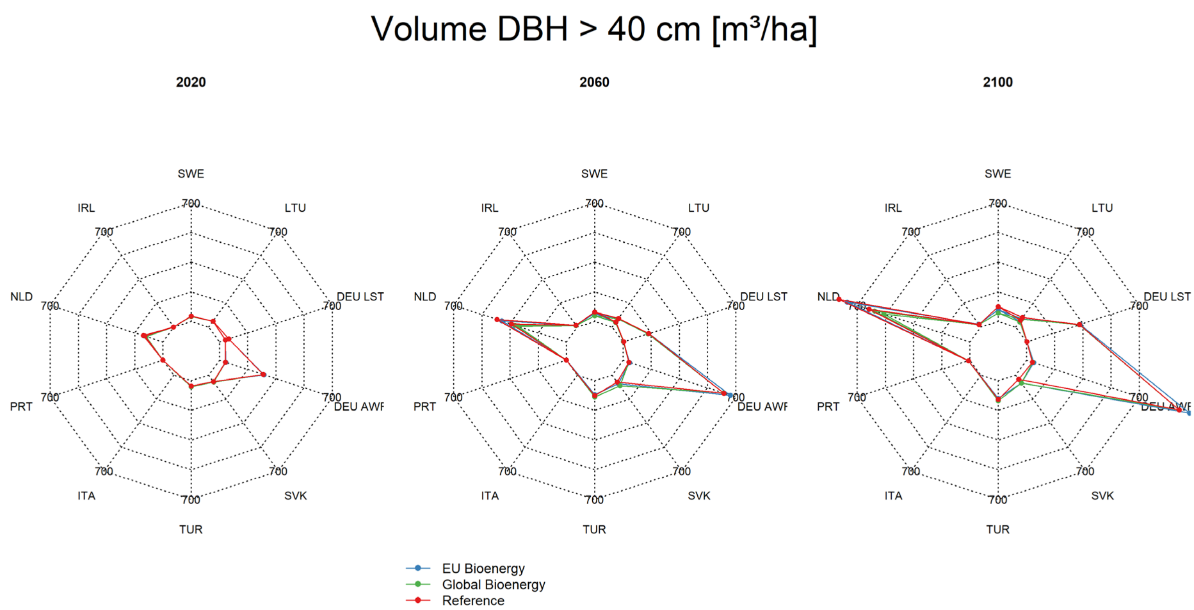

Figure 13 Volume of trees with a diameter at breast height (dbh) of more than 40 cm (m³/ha) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

Another prominent indicator for biodiversity which, in addition, plays an important role in the forest carbon cycle is the coarse deadwood volume per unit area (Figure 14). Starting generally with values between 10 and 20 m³/ha, all CSAs except Italy and Slovakia and Germany as a special case show a slight increase. In Germany AWF, the Nature Protection aFMM ends up with almost 90 m³/ha. The same aFMM also considerably increases the deadwood volume in Germany LST, but the dry and poor sites hinder a quick accumulation as obtained for Germany AWF. The other extreme aFMM in Germany (Production Forest) even lowers the coarse deadwood volume. In both German CSAs, where the aFMM lowers the deadwood volume, there is a considerable spread among the global frame scenarios with Reference leading to the highest and Global Bioenergy leading to the lowest deadwood volumes. In the latter two scenarios considerable amounts of wood and harvest residues that remain in the forest in the Reference scenario are extracted and put into use, mostly for energy generation.

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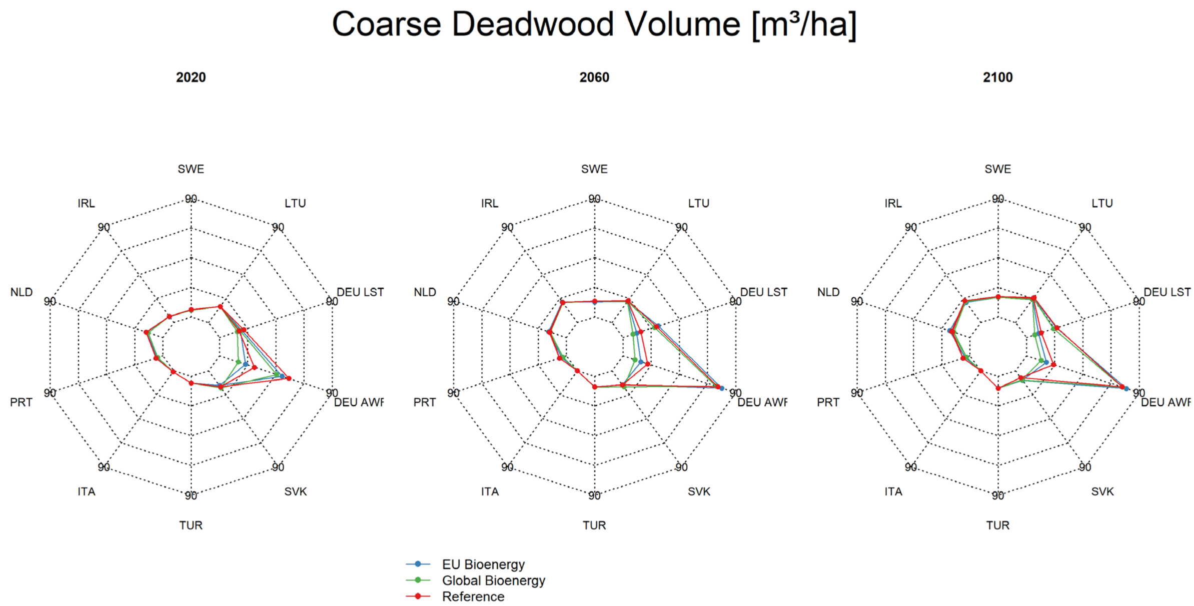

Figure 14 Coarse deadwood volume (m³/ha) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

2.3 Carbon Related Variables

The carbon evaluation tool developed in ALTERFOR (Biber and Black 2018) allows estimates of the most important carbon stocks in the forest, in wood products and substitution effects due to using wood instead of other raw materials. The carbon balances of these components can be evaluated separately and add up to the total carbon balance of the forest area of interest.

The sum carbon balances off the important above and belowground forest bound carbon stocks are shown in Figure 15. In the majority of the case studies, this carbon balance is positive (up to 3 tC/ha/year) in the initial phase, but considerably shrinks (while still keeping positive values after 100 years. Exceptions are Lithuania and Slovakia with almost balanced forest carbon stocks throughout the whole simulation time span. The strongest exception is Germany, especially the AWF area, were there is an enormous spread among the aFMMs. Initially, the production forest aFMM harvests all over-mature (from this concept's angle of view) stands, leading to a strongly negative forest carbon balance (~ -4 tC/ha/year), with considerable global frame scenario differentiation. In the middle of the simulation time span, this aFMM leads to balanced forest carbon stocks. But in the end, the second generation's harvest wave occurs, reducing the balance down again to values of about -3 tC/ha/year. Totally different is the balance for the Nature Protection Forest aFMM in the German AWF region. Immediately after the beginning of the simulation, the balance is very high (3 tC/ha/year), but as the growing stock increases the net C uptake (i.e. the forest bound carbon balance) shrinks continuously, with however considerably positive values (~ 1.4 tC/ha/year) still after 100 years.

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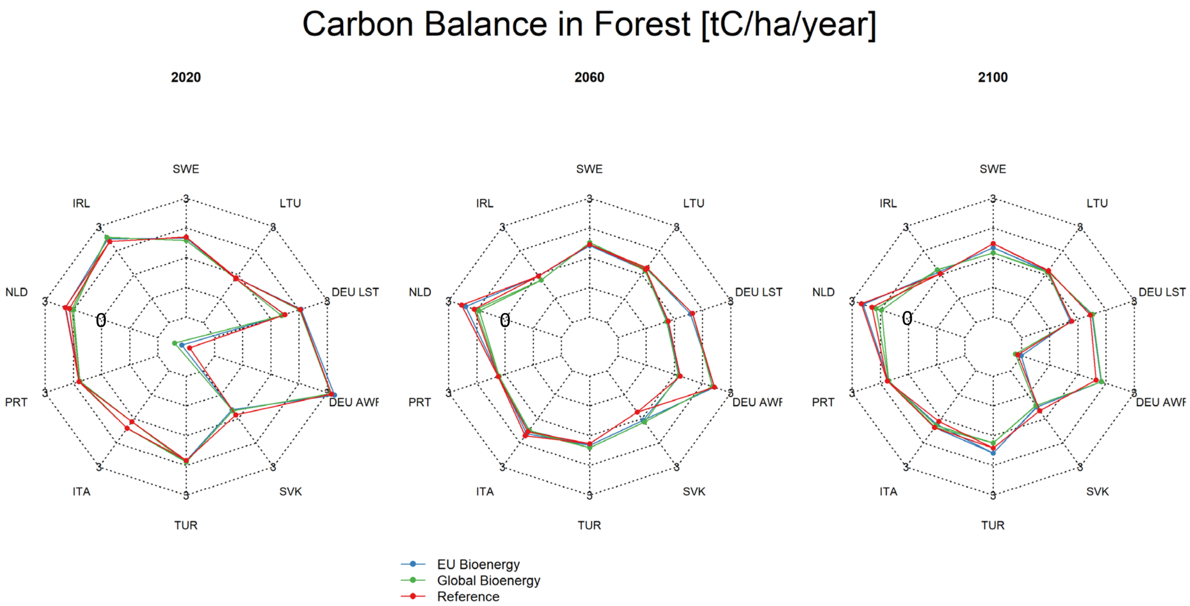

Figure 15 Forest carbon balance (tC/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

Much more equalized is the carbon balance in the product stocks that can be attributed to the forest area of interest. Almost every CSA has balance values around zero for the whole simulation period (Figure 16). Portugal is as an exception with a consistently positive balance of about 0.7 tC/ha/year. Due to the two harvesting waves in the Production forest aFMM in the German AWF region, there is an extreme initial peak and a smaller one at the end of the simulation. These are just the logical consequence of the two corresponding troughs in the forest bound carbon balance. Large portions of the material being harvested (reducing the forest C balance) are converted into products, thus increasing the product C stock balance.

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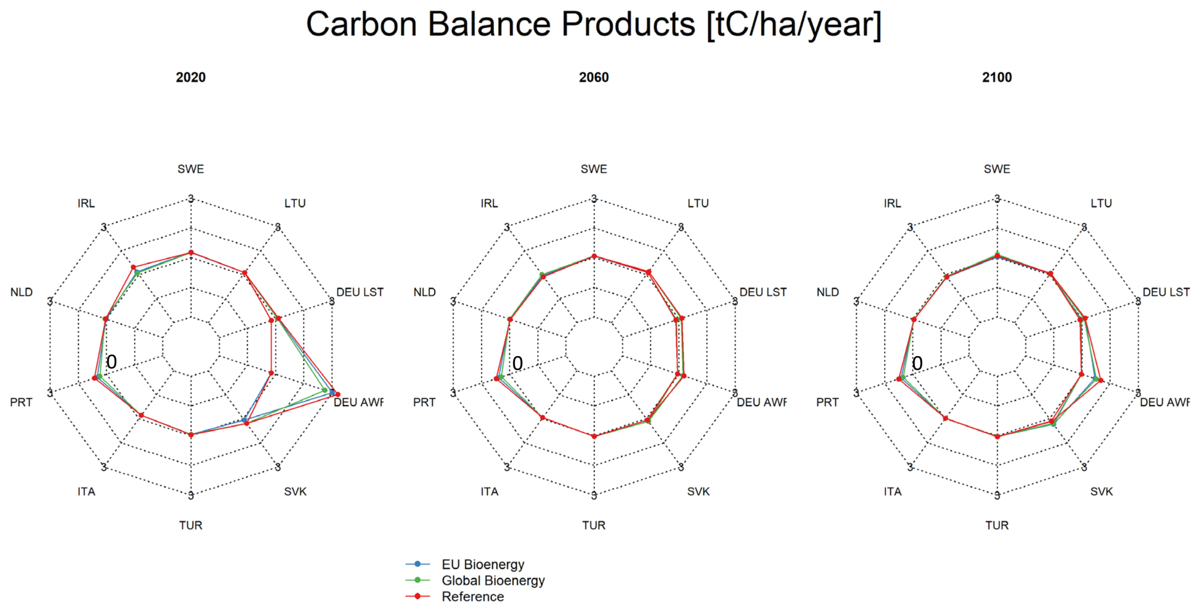

Figure 16 Wood product carbon balance (tC/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

As almost all aFMMs continuously provide timber, be it balanced or fluctuating, there are always slightly positive C emission savings (Figure 17). Total zero emission savings result only from the Nature Protection aFMMs in both German CSAs. In contrast, when much timber is put into use, the emission savings are high. Thus, the two harvesting waves in the German AWF CSA are visible also in terms of emission savings.

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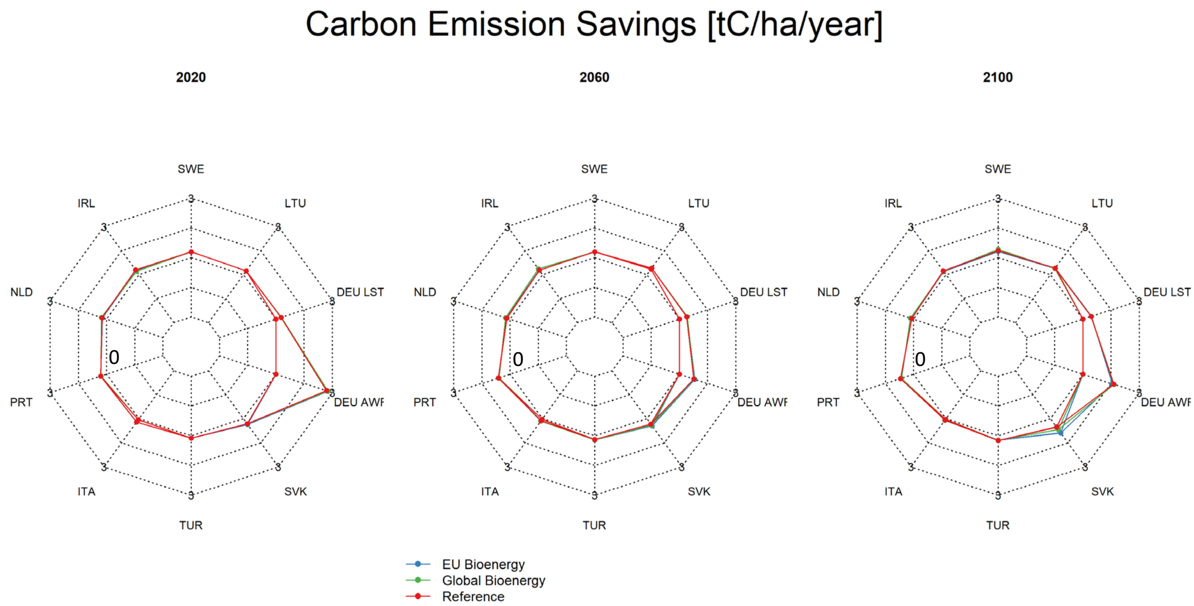

Figure 17 Carbon emission savings (tC/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

The total carbon balance (Figure 18) is the sum of all three C balance components shown above (forest bound, product bound balance, and emission savings). There is a general tendency of shrinking balances throughout the simulation time span, but with the exception of Germany AWF and LST in one aFMM at the end of the simulation have still positive values. The highest balances on the long run (almost 3 tC/ha/year) are obtained for the Netherlands and Portugal, however for different reasons. While in the Netherlands the positive C balance almost solely comes from an increase in the forest bound C, while there is a considerable contribution by a positive product balance and emission savings in Portugal. Due to increasing forest stocks in the beginning, the Irish CSA has a very high total balance which drops rapidly back to near zero from the middle of the simulation period. Generally, based on observing Figures 15 to 18 together, it becomes evident that changes in the forest-bound C stocks are most decisive for the behaviour of the total C balance. However, from the initial strong and later continuously weaker reactions of the forest C balance it is evident that this is the temporary effect of applying a new FMM to a forest which has been managed otherwise before. So, the aFMMs are gradually transforming the forest into a new status of sustainability which corresponds to the specifics of the aFMM. In the long run (and without large forest damages occurring), therefore, the forest C balance will be zero as well as the product bound C balance. The only remaining positive component of the total balance would be the emission savings.

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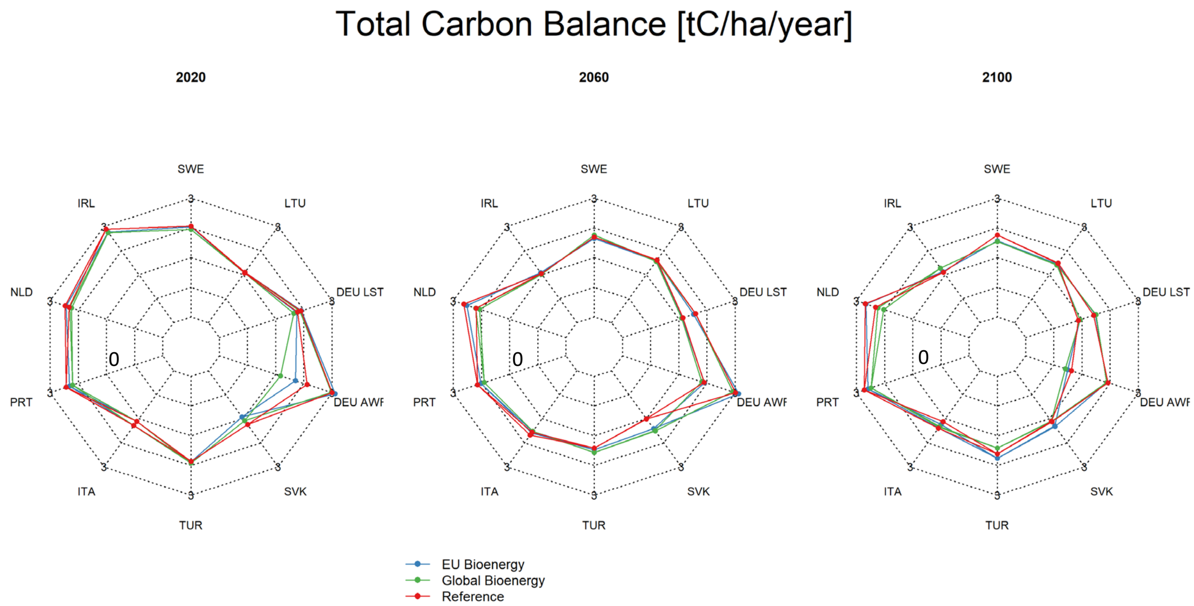

Figure 18 Total carbon balance (tC/ha/year) projections in the single case studies for the three global frame scenarios (EU Bioenergy, Global Bioenergy, Reference), shown for the years 2020, 2060, and 2100.

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3 Ecosystem Services Reports by the Expert Group

In this section we provide the case study overarching ES assessments as provided by the ALTERFOR ES Experts.

3.1 Biodiversity

Adam Felton and Matts Lindbladh

The LCCs provided output which varied in the approach used and, as expected, the conclusions arrived at. First, there was general but incomplete overlap in the scenarios assessed, with three CSAs adding "Business as usual" to the 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. In addition, and more importantly, the CSAs differed in whether the models were applied comprehensively, or selectively, to the alternative FMMs (aFMMS) adopted. For example, four countries 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 considered. In contrast, three countries coupled the production "intensity" of the aFMMs adopted, and the scenarios assessed. This approach was generally motivated by the underlying premise of the scenarios within which lower levels of GHG emission were achieved, correspondingly required more intensive forest-dependent climate change mitigation. Notably, in those CSAs for which this linkage occurred, it is of direct relevance to the interpretation of outcomes, as there is thus an inherent potential trade-off between the extent of anthropogenic climate change, and the compatibility of forest management with habitat provision for biodiversity. 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 may be associated with reduced habitat availability, and vice versa, with corresponding implications for how modelling outcomes focused on resultant habitat availability can be interpreted.

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 focused on the implications of different fuel treatments for preventing forest fires; Slovakia assessed the implications of increasing 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 that are likely to have strong implications for resultant outcomes and the breadth of alternative management directions available. For example, in Portugal recent policy changes restrict 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.

As in D3.2, the majority of LCCs analyzed differences between the scenarios in terms of changes to a number of individual metrics (e.g. % broadleaf, large trees, etc.) of regional relevance to biodiversity, whereas the other LCCs combined relevant metrics into single composite scores, which were then

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often disaggregated for interpretation. With respect to the combined approaches Germany expanded upon their "Fuzzy logic" concept, whereas the Netherlands (eight tree species composition, structural and disturbance indicators) and Portugal (tree species proportion and shrub cover) adopted their own means of deriving value functions for contrasting net biodiversity outcomes, comprised from different habitat indicators.

These differences in approach, scenario consideration, aFMM adoption, and associated interactions, understandably translated into LCC specific outcomes. For example, in Germany the best outcomes for biodiversity were strongly linked to the adoption of the "nature" or "multifunctional" alternative FMMs, rather than to differences in the scenarios per se. For Portugal however, positive outcomes were dictated to a large extent by the aFMM considered, and the fuel management strategy employed. For Italy, habitat and recreation considerate forestry had the most positive outcomes for biodiversity, as did the promotion of deciduous alternatives in Lithuania. In contrast, and as noted earlier, other countries with strong linkages between the specific scenario considered and the aFMMs adopted, often found that the EU Bioenergy scenario resulted in relatively high positive outcomes for biodiversity. This was the case for Sweden, Netherlands, and Slovakia. In other countries, such as Ireland and Portugal, the relative differences between scenarios were small or inconsequential.

In this regard, the Reference scenario varied widely in terms of its associated implications for biodiversity. In some countries, it was coupled with less intensive forestry measures, with associated implications for biodiversity. For example, in the Netherlands, the Reference scenario used was associated with slightly better biodiversity outcomes than the Global Bioenergy scenario. In Sweden, benefits associated with the Reference scenario were presumably linked both to positive growth rates and the choice of alternative FMMs, which in combination benefited broadleaf tree species (a key contributor to habitat provision in this region). Nevertheless, the concerns that can be raised about the use of more intensive silvicultural prescriptions in the EU and Global Bioenergy scenarios, must once again be balanced against the adverse implications that climate change itself raises for biodiversity.

Finally, it should be noted that individual habitat indicators often diverged within countries, with associated implications for which species are likely to benefit under the different scenarios and FMM alternatives implemented. Whereas many countries projected positive outcomes for biodiversity under either specific scenarios, or as associated with the uptake of specific FMM alternatives, not all habitat indicators behaved consistently. For example, in the Slovakia CSA increases in broadleaf trees are consistently projected across all scenarios, but these improvements are countered to some extent by consistent decreases across scenarios in their understory index, and inconsistent outcomes across scenarios for large tree volumes. Such complexities can be expected when a country tries to balance the need for multiple ESs, and match differing climate change mitigation and adaptation efforts to varying extents of climate warming.

Nevertheless, these differences in outcome highlight the variety of determinants that are operating within these CSAs to dictate the future biodiversity of production forest lands. For many CSAs, policy decisions, initial forest states, and the coupling of different suites of aFMMs to the global frame scenarios all combine to result in the understandably variable and context specific outcomes of this assessment. Nevertheless, despite the inconsistency in outcomes, general consistency among CSAs in terms of which forest characteristics overlapped more or less with forest biodiversity goals remains.

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In this regard, 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, can be seen as consistent strategies for achieving regional biodiversity goals across much of Europe. Because of this, we see the Fuzzy Logic approach used in the German CSAs as a highly promising standardized means of integrating and interpreting these outcomes for cross country comparison.

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3.2 Timber Provision

Maarten Nieuwenhuis, Eva-Maria Nordström and Peter Biber

3.2.1 Introduction

The ALTERFOR standard variables related to timber services are total Harvest volume, Assortment volumes (Sawlog, Pulpwood and Harvest residues), Standing volume and Volume increment. While almost all CSAs provided the full set of these variables in their simulation result reports (see MS12 document), often only a part of them was considered for their specific reports about timber provision (which are the basis for this chapter, see Table 3). In some cases, additional variables were included in the CSA reports, such as basal area, but these are not included here as there was no consistency.

In some CSA reports, the results for the introduction of individual aFMMs were reported separately, but in other reports all the aFMMs were introduced as a complete set, resulting in only one result per global frame scenario (see tables in individual CSA summary reports below).

In some reports, comparisons were made with the cFMM results. It was decided earlier that these comparisons did not make sense in several CSAs, as the models and data used to produce these results (reported in D3.2) had been changed, updated and improved for the aFMM analysis. However, is several CSA the cFMM analysis was repeated with the updated models and data, and therefore comparison between cFMM results and those after inclusion of the aFMMs made sense.

In a few CSA, comparisons were also made with the results for a scenario without climate and price changes (the Base scenario).

Table 3 Variables used in the single CSAs' timber services assessment

CSA	Harvest volume	Sawlog	Pulpwood	Harvest residues	Standing volume	Volume increment
Germany/AWF	x				x	x
Germany/LST	x				x	x
Ireland	x	x	x		x	x
Italy	x				x	x
Lithuania	x	x	x	x	x	x
Netherlands	x[1]					x[1]
Portugal	x	x	x	x	x	x
Slovakia	x				x	x
Sweden	x	x	x	x	x	x
Turkey	x				x	x

[1] No volumes were reported, but harvest/increment ratio was reported.

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3.2.2 Results per CSA

Germany/AWF (Augsburg)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Multifunctional Nature conservation Production forest	Multifunctional Nature conservation Production forest	Multifunctional Nature conservation Production forest

Fuzzy logic was used in the assessment of sustainable timber provision, similar to that used in D3.2.

Overall, there are no great differences between results for the global frame scenarios, but there are significant differences between the aFMMs.

For the Multifunctional aFMM, constant medium levels of harvest volumes were produced (c. 10-11 m^3 ha^{-1} yr^{-1}). Similarly, the Standing volume and Volume increment were at a constant level.

In the Nature conservation aFMM, no timber harvesting takes place, so harvest volume is zero. This results in a large increase in standing volume from 500 to 1100 m^3 ha^{-1}.

In the Production forest aFMM, timber harvest volumes fluctuate substantially (reflecting the age class distribution): in 2020 – 40 m^3 ha^{-1} yr^{-1}, 2070 – 5, 2100 – 27 and 2120 13 m^3 ha^{-1} yr^{-1}. Standing volume and increment fluctuate in accordance with the development of the age class distribution.

Germany/LST – Lieberose Schlaubetal

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Multifunctional Nature conservation Production	Multifunctional Nature conservation Production	Multifunctional Nature conservation Production

Fuzzy logic was used in the assessment of sustainable timber provision, similar to that used in D3.2.

Overall, there are no great differences between results for the global frame scenarios and the trends are similar to those for Germany/AWF, although at much lower levels reflecting the poor site conditions.

In the Multifunctional and Conservation aFMMs, timber harvest levels were relatively constant at 5 to 7 m^3 ha^{-1} yr^{-1}, whereas in the Production forest aFMM the volumes fluctuated more, between 4 and 9 m^3 ha^{-1} yr^{-1}.

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Standing volume was constant in the Timber production aFMM, at 250 m^3 ha^{-1}, dropped slightly in the Multifunctional aFMM (to 200 m^3 ha^{-1}) and increased dramatically in the Conservation aFMM (to m^3 ha^{-1}).

The trend in Volume increment is generally downwards, most so in the Multifunctional aFMM, from 7.5 to 4.5 m^3 ha^{-1} yr^{-1}, due to the actively promoted increasing shares of deciduous species. In the Production forest aFMM, the increment increases slightly initially, and then decreases, from 7.5 to 9.0 to 7.3 m^3 ha^{-1} yr^{-1}.

Ireland

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM set reported	Environmentally constrained profit maximisation	Environmentally constrained profit maximisation	Environmentally constrained profit maximisation

Harvest volumes were similar for the three global frame scenarios, they fluctuated reflecting the age class distribution in the CSA: 2010 – 2.5 m^3 ha^{-1} yr^{-1}, 2040 – 10, 2065 – 2.5 and 2110 – 5 m^3 ha^{-1} yr^{-1}. The peaks were slightly lower for the aFMM than the cFMM results, due to the lower lodgepole pine stocking in the aFMM.

Standing volume increased in all scenarios, starting around 160 m^3 ha^{-1} in 2016 and finishing at 270, 220, 230, 225 m^3 ha^{-1} for the cFMM, Reference, EU Bioenergy and Global Bioenergy scenarios, respectively. The increase was rapid between 2020 and 2030 and slightly declined between 2040 and 2060 due to heavy clearfelling during this time. After 2060, standing volume increased for the remainder of the planning horizon. The higher ending standing volume in the cFMM Reference scenario was due to lower clearfelling rates, which allowed stands to grow old and accumulate volume.

Sawlog volumes peaked at the same time as the total harvest volume (2050) at 4.5 m^3 ha^{-1} yr^{-1}. Then they decreased from 2050 to 2065 to 1-1.5 m^3 ha^{-1} yr^{-1} due to the replacement of Sitka spruce by lodgepole pine. Pulpwood volumes increased in each global frame scenario, due to the switch to lodgepole pine. For the aFMM, the sawlog and pulpwood volumes were lower than for the cFMM. In the Global Bioenergy scenario, pulpwood volume was higher than in the other two due to the higher pulpwood prices.

The volume increment was overall very similar for the frame scenarios, with a decrease when the aFMM is used, starting at 8 m^3 ha^{-1} yr^{-1} and increasing to 12 m^3 ha^{-1} yr^{-1} in the first 20 years, and then decreasing to 6-7 m^3 ha^{-1} yr^{-1} over the remainder. The increment for the aFMM was slightly lower than for the cFMM due to the lower lodgepole pine stocking.

The aFMM produced a higher NPV from a smaller clearfelling area, due to the lower costs associated with the low stocking lodgepole pine option.

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Italy

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Recreational Production	Recreational Production	Recreational Production

In the cFMMs there was a very low harvest intensity. The use of the Production aFMM could lead to an increase.

Harvest volume trends were very similar in the global frame scenarios, but volumes were slightly higher in the Global Bioenergy scenario than in the others. Overall between 1.0 and 3.0 m^3 ha^{-1} yr^{-1}. Both aFMMs resulted in mainly firewood and chips, while the Production aFMM also resulted in pine sawlogs. The volumes fluctuated in the Production aFMM reflecting the rotation time of the coppice. No harvest residues were to be left in the stands, to reduce fire risk and to improve the appearance, but volumes harvested were not reported.

The standing volume increased for both aFMMs in all scenarios, but not as much as for the cFMMs. The Standing volume at the end of the planning period was slightly higher for the Production aFMM than for the Recreation aFMM, at 275 compared to 225 m^3 ha^{-1}.

Volume increment was higher for the Production aFMM (fluctuating between 3 and 6 m^3 ha^{-1} yr^{-1}) than for the Recreation aFMM (constant at 3.5 m^3 ha^{-1} yr^{-1}).

Lithuania

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Economic rotation Financial rotation Deciduous forest Potential EU habitats	Economic rotation Financial rotation Deciduous forest Potential EU habitats	Economic rotation Financial rotation Deciduous forest Potential EU habitats

The cFMM resulted in increasing harvest volumes, least so in the Global Bioenergy scenario. The introduction of the aFMMs led to further increases, higher for the Economic (aFMM 1) and Financial Rotation (aFMM 2) than for Deciduous forest (aFMM 3) and Potential EU habitats (aFMM 4), especially during the middle of the planning period, but they reached similar levels at the end. Starting level 2.5 to 4 m^3 ha^{-1} yr^{-1}, ending levels 6.5-7.5 m^3 ha^{-1} yr^{-1} for the Global Bioenergy and EU Bioenergy scenarios and 7-8 m^3 ha^{-1} yr^{-1} for the Reference scenario.

Sawlog volumes displayed similar trends as the total harvest volume, starting at 1-1.5 and ending at 3.5 m^3 ha^{-1} yr^{-1}. Pulpwood volumes were relatively stable after increasing in the first 30 years, ending at 2-2.5 m^3 ha^{-1} yr^{-1}. Harvest residue volumes increased from 0.5 to 1.2 m^3 ha^{-1} yr^{-1} for all global frame scenarios and aFMMs. The aFMMs 1 and 2 produced 0.5 m^3 ha^{-1} yr^{-1} more sawlogs and 0.3 m^3 ha^{-1} yr-

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[1] more pulpwood compared to the cFMM. The aFMM 3 and 4 produced less sawlogs and pulpwood than the cFMM, but only by 2 or 3%.

Standing volumes increased for all scenarios and aFMMs (from 230 m^3 ha^{-1}) but were highest for the Reference scenario (305-345 m^3 ha^{-1} at the end of the planning period for all aFMMs), compared to 285-320 m^3 ha^{-1} for the Global Bioenergy and 290-325 m^3 ha^{-1} for the EU Bioenergy scenario.

Volume increment generally increased for all scenarios and aFMMs, from 7.5-8 to 9-9.5 m^3 ha^{-1} yr^{-1} for the Global Bioenergy and EU Bioenergy scenarios and to 10-10.5 m^3 ha^{-1} yr^{-1} for the Reference scenario. The increment was slightly higher for the first two aFMMs than for the latter two, during the period 2060-2100.

The highest profit was associated with the Global Bioenergy scenario, even though it results in lower growth, but the very high timber prices more than compensate for this.

Netherlands

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Reference gfdl Reference hdgem	Wood production	Bioenergy gfdl Bioenergy hdgem

The results for the Netherlands are not reported in the standard format for the global frame scenarios, so less information can be extracted. It is stated that the results are reported independent of the global scenarios.

Results are presented for a Production index, which is made up of a combination of sufficiency (harvest volume divide by demand), assortment balance (proportion of sawlogs in the harvest volume), sustainability (harvest volume over increment) and efficiency (also harvest volume over increment). This index goes down in all scenarios and for both aFMMs, by about 25% in general, but more so for the Wood production aFMM and less so in the Reference scenario. This reduction is caused by the fact that harvest volumes are always below volume increment, reducing the efficiency and sufficiency values. The sustainability and assortment balance values are consistently at their maximum.

The model used does not include regeneration, resulting in a forest that gets older and older, which impacts considerably on the results.

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Portugal

	Frame scenario		
	Reference[1]	**EU Bioenergy**[1]	**Business as usual**[1]
aFMM vs cFMM	Stakeholder solution Max volume solution	Stakeholder solution Max volume solution	Stakeholder solution Max volume solution

[1] These are local scenarios – Global Bioenergy is not considered due to lack of data, instead there is a Business as usual scenario with no climate change.

Harvest volumes were fluctuating but increasing over the planning period and were equal for all frame scenarios: 2020 – 0.5 m^3 ha^{-1} yr^{-1}, 2040 - 1.5, 2080 – 1.0, 2090 – 1.8 and 2100 – 1.5 m^3 ha^{-1} yr^{-1}. The volumes reflected the fluctuating standing volume values.

Sawlog volume was similar for all frame scenarios and was fluctuating: 2020 – 0 m^3 ha^{-1} yr^{-1}, 2050 – 0.22, 2060/80 – 0, 2090 – 0.2 and 2100 – 0.03 m^3 ha^{-1} yr^{-1}. Pulpwood volumes also fluctuated, between 1.0 and 1.5 m^3 ha^{-1} yr^{-1} between 2030 and 2100 after starting at 0.5 m^3 ha^{-1} yr^{-1}. Harvest residues volumes started at 0.035 m^3 ha^{-1} yr^{-1} and then fluctuated between 0.07 and 1.00 m^3 ha^{-1} yr^{-1}.

Standing volume was equal for all frame scenarios and fluctuated: 2010 – 30 m^3 ha^{-1}, 2025 – 55, 2065 – 20, 2080 – 65 and 2120 – 30 m^3 ha^{-1}.

The volume increment was very similar for the different frame scenarios, but slightly higher for the Reference one. As for all the other volumes, increment fluctuated: 2020 – 3.5 m^3 ha^{-1} yr^{-1}, 2030 – 0, 2050 – 2, 2060 – 0, 2070 – 6, 2080 – 0, 2090 – 2 and 2100 – 0 m^3 ha^{-1} yr^{-1}.

Overall, the cFMMs continue to dominate but there is some introduction of aFMMs at very low levels.

Slovakia

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM / aFMM set reported	Restitution of ownership Biodiversity Biodiversity & Restitution	Restitution of ownership Biodiversity Biodiversity & Restitution	Restitution of ownership Biodiversity Biodiversity & Restitution

Results were reported for the three global frame scenarios as well as for a Base scenario that reflects no climate and price changes.

The harvest volume followed similar trends for all aFMMs in the Base, EU Bioenergy and Global Bioenergy scenarios, starting at 2.0 m^3 ha^{-1} yr^{-1}, with a substantial increase to 6.5-7.5 m^3 ha^{-1} yr^{-1} followed by a drop in the last 20 years to 5.5-6.5 m^3 ha^{-1} yr^{-1}. In the Reference scenario, the volume rises from

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2.0 to 5.5 m^3 ha^{-1} yr^{-1}in the first 15 years, then decrease to 4.0 m^3 ha^{-1} yr^{-1}over the remainder of the planning period.

Standing volume trends are similar (first increasing, then decreasing) for the aFMMs but occur at different levels for the Base and global frame scenarios. In all scenarios, the starting standing volume is 200 m^3 ha^{-1}, increasing to 240 m^3 ha^{-1} for the EU Bioenergy and Global Bioenergy scenarios, to 220 m^3 ha^{-1} for the Reference and 250 m^3 ha^{-1} for the Base scenario. The decrease is largest in the Reference scenario, to 120 m^3 ha^{-1}, next largest for Global Bioenergy to 140 m^3 ha^{-1}, then EU Bioenergy to 170 m^3 ha^{-1} and in the Base scenario the end level is 170 m^3 ha^{-1}. The broadleaf component increases in all scenarios and for all aFMMs after an initial decrease: starting at 48%, dropping to 40-43% and increasing to 50-56%.

The volume increment is constant at 7.5 m^3 ha^{-1} yr^{-1}in the Base scenario for all aFMMs, but it decreases in the global frame scenarios. The largest decrease occurs in the Global Bioenergy scenario, from 7.5 to 4.0 m^3 ha^{-1} yr^{-1}, followed by a drop from 7.5 to 5.0 m^3 ha^{-1} yr^{-1} in the Reference one and from 7.5 to 6.0 m^3 ha^{-1} yr^{-1} in the EU Bioenergy scenario. These trends were similar for all aFMMs in each scenario.

Sweden

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM set reported	Reference	EU Bioenergy	Global Bioenergy

Harvest volumes increased substantially over the planning period in each global frame scenario: 68 % in Global Bioenergy, 16% in EU Bioenergy and 24% in the Reference scenario.

The sawlog share dropped in all scenarios from 65 to 55%, with a substantial volume of hybrid larch in the Global Bioenergy scenario volume. On the other hand, in the Reference and EU Bioenergy scenarios, more oak and birch volume will occur. The harvest residue volume was 50% higher in the Global Bioenergy scenario than in the other two, reflecting higher harvest levels and less restrictive rules about site suitability for residue removal.

Standing volume (in the production forests) decreased in the Global Bioenergy scenario when cFMM was used but increased in all scenarios when the aFMM set was introduced, from 180 to 350 m^3 ha^{-1}.

Volume increment increased in all scenarios when the aFMM set was included, from 7 to 14 m^3 ha^{-1} yr^{-1} in the Reference, 7 to 11 m^3 ha^{-1} yr^{-1} in the EU Bioenergy and 7 to 10 m^3 ha^{-1} yr^{-1} in the Global Bioenergy scenario.

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Turkey

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM set reported	CCF	CCF	CCF

Harvest volumes followed similar trends in the three global frame scenarios, increasing from 13 to 27 m^3 ha^{-1} yr^{-1}. Smaller dimensions were harvested over time, and the introduction of the aFMM set resulted in more thinning and less clearfelling compared to the situation for the cFMM.

Standing volume increased in all scenarios, from 160 to 300 m^3 ha^{-1}. Compared to the standing volume for cFMM only, the volume increased when the aFMM set was added.

Volume increment trends were similar for the three global frame scenarios, but the ending volume was higher in the Global Bioenergy scenario, at 5.3 m^3 ha^{-1} yr^{-1}, than in the other two scenarios.

There were 1000 ha in the CSA that were suitable for afforestation, but this was not included in the reported results as this area was considered important for wildlife. However, if timber production needs to be further increased, afforestation of (part of) this area could be investigated.

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3.2.3 Summary

Harvest volume

Harvest volume increased in four countries: Lithuania, Slovakia, Sweden and Turkey (Table 4). In other countries harvest volumes were stable or fluctuating. There were no strong differences between global frame scenarios, but some substantial differences between aFMMs in a few CSA, especially Germany/AWF and Sweden, and to a lesser extent in Slovakia.

Table 4 Harvest volume (m3 ha-1 yr-1) trends in the three global frame scenarios (↑ increasing, ↑↑ substantially increasing, ↓ decreasing, ↓↓ substantially decreasing, ↔ stable, ↕ fluctuating, ↕↑ fluctuating but overall increasing, etc.)

CSA	aFMM / aFMM set	Global frame scenario		
		Reference	EU Bioenergy	Global Bioenergy
Germany/AWF	Multifunctional	↔ (10-11)	↔ (10-11)	↔ (10-11)
	Nature conservation	0	0	0
	Production forest	↕ (5-40)	↕ (5-40)	↕ (5-40)
Germany/LST	Multifunctional	↔ (5-7)	↔ (5-7)	↔ (5-7)
	Nature conservation	0	0	0
	Production forest	↕ (4-9)	↕ (4-9)	↕ (4-9)
Ireland	Environmentally constrained profit maximisation	↕ (2.5-10)	↕ (2.5-10)	↕ (2.5-10)
Italy	Recreational	↔ (1.5)	↔ (1.5)	↔ (2.0)
	Production	↕ (1.0-2.0)	↕ (1.0-2.0)	↕ (1.5-3.0)
Lithuania	Economic rotation	↑	↑	↑
	Financial rotation	↑	↑	↑
	Deciduous forest	↑	↑	↑
	Potential EU habitats	↑	↑	↑
Netherlands	Reference gfdl	↔	↔	↔
	Reference hdgem	↔	↔	↔
Portugal	Combination of low intensity pine management, broadleaf & sawlog, cork oak and riparian aFMMs	↕↑	↕↑	↕↑
Slovakia	Restitution of ownership	↑ (end 4.0)	↑ (end 6.5)	↑ (end 6.5)
	Biodiversity	↑ (end 4.0)	↑ (end 6.5)	↑ (end 6.5)
	Biodiversity & Restitution	↑ (end 4.0)	↑ (end 6.5)	↑ (end 6.5)
Sweden	Reference	↑ (up 24%)		
	EU Bioenergy		↑ (up 16%)	
	Global Bioenergy			↑↑ (up 68%)
Turkey	CCF	↑↑	↑↑	↑↑

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Standing volume

Standing volume generally followed an upward or stable trend, except for Slovakia and the Multi-functional aFMM in the German/LST CSA (Table 5). There were very few differences between the results for each aFMM / aFMM set in the global frame scenarios.

Table 5 Standing volume (m3 ha-1) trends in the three global frame scenarios (↑ increasing, ↑↑ substantially increasing, ↓ decreasing, ↓↓ substantially decreasing, ↔ stable, ↕ fluctuating, ↕↑ fluctuating but overall increasing, etc.)

CSA	aFMM / aFMM set	Global frame scenario		
		Reference	**EU Bioenergy**	**Global Bioenergy**
Germany/AWF	Multifunctional	↔	↔	↔
	Nature conservation	↑↑ (500-1100)	↑↑ (500-1100)	↑↑ (500-1100)
	Production forest	↕↕	↕↕	↕↕
Germany/LST	Multifunctional	↓ (end 200)	↓ (end 200)	↓ (end 200)
	Nature conservation	↑↑ (end 650)	↑↑ (end 650)	↑↑ (end 650)
	Production forest	↔ (250)	↔ (250)	↔ (250)
Ireland	Environmentally constrained profit maximisation	↕↑	↕↑	↕↑
Italy	Recreational	↑ (end 225)	↑ (end 225)	↑ (end 225)
	Production	↑ (end 275)	↑ (end 275)	↑ (end 275)
Lithuania	Economic rotation	↑↑ (end 325)	↑ (end 310)	↑ (end 305)
	Financial rotation	↑↑ (end 325)	↑ (end 310)	↑ (end 305)
	Deciduous forest	↑↑ (end 325)	↑ (end 310)	↑ (end 305)
	Potential EU habitats	↑↑ (end 325)	↑ (end 310)	↑ (end 305)
Netherlands	Reference gfdl	↑	↑	↑
	Reference hdgem	↑	↑	↑
Portugal	Combination of low inten-sity pine management, broadleaf & sawlog, cork oak and riparian aFMMs	↕	↕	↕
Slovakia	Restitution of ownership	↕↓ (end 120)	↕ (end 170)	↕↓ (end 140)
	Biodiversity	↕↓ (end 120)	↕ (end 170)	↕↓ (end 140)
	Biodiversity & Restitution	↕↓ (end 120)	↕ (end 170)	↕↓ (end 140)
Sweden	Reference	↑↑ (180 to 350)		
	EU Bioenergy		↑↑ (180 to 350)	
	Global Bioenergy			↑↑ (180 to 350)
Turkey	CCF	↑↑ (160 to 300)	↑↑ (160 to 300)	↑↑ (160 to 300)

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Volume increment

There were mixed results for volume increment, with several CSAs showing an increase (Lithuania, Sweden and Turkey) and others a decrease (Germany/LST, Ireland, Netherlands and Slovakia) in the increment (Table 6). No great differences in the results for the three global frame scenarios, except for Slovakia, Sweden and Turkey. There were also differences in the results for the different aFMMs in two CSAs (Germany/AWF and Germany/LST).

Table 6 Volume increment (m3 ha-1 yr-1) trends in the three global frame scenarios (↑ increasing, ↑↑ substantially increasing, ↓ decreasing, ↓↓ substantially decreasing, ↔ stable, ↕ fluctuating, ↕↑ fluctuating but overall increasing, etc.)

CSA	aFMM / aFMM set	Global frame scenario		
		Reference	EU Bioenergy	Global Bioenergy
Germany/AWF	Multifunctional	↔	↔	↔
	Nature conservation	↔	↔	↔
	Production forest	↕↕	↕↕	↕↕
Germany/LST	Multifunctional	↓↓	↓↓	↓↓
	Nature conservation	↓	↓	↓
	Production forest	↕↓	↕↓	↕↓
Ireland	Environmentally constrained profit maximisation	↕↓	↕↓	↕↓
Italy	Recreational	↔	↔	↔
	Production	↕	↕	↕
Lithuania	Economic rotation	↑	↑	↑
	Financial rotation	↑	↑	↑
	Deciduous forest	↑	↑	↑
	Potential EU habitats	↑	↑	↑
Netherlands	Reference gfdl	↓	↓	↓
	Reference hdgem	↓	↓	↓
Portugal	Combination of low intensity pine management, broadleaf & saw-log, cork oak and riparian aFMMs	↕	↕	↕
Slovakia	Restitution of ownership	↓ (end 5.0)	↓ (end 6.0)	↓ (end 4.0)
	Biodiversity	↓ (end 5.0)	↓ (end 6.0)	↓ (end 4.0)
	Biodiversity & Restitution	↓ (end 5.0)	↓ (end 6.0)	↓ (end 4.0)
Sweden	Reference	↑↑ (end 14)		
	EU Bioenergy		↑ (end 10)	
	Global Bioenergy			↑ (end 11)
Turkey	CCF	↑ (end 4.9)	↑ (end 4.9)	↑ (end 5.3)

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3.2.4 Conclusion

There doesn't appear to be a strong trend in the harvest volumes when all CSAs and aFMMs/ aFMM sets are considered together. However, none of the results indicate a reduction in volume, while 11 CSA / aFMM combinations result in volume increases, six in stable volumes and five in fluctuating volumes. So, overall the indication is that harvest volumes will increase, but only marginally.

The trend in standing volume is somewhat more pronounced, with 14 CSA / aFMM combinations resulting in increasing volumes, one in a decrease, five in volume fluctuations, and two in stable volumes.

Although the trends in both harvest volumes and standing volumes are generally upwards, volume increment does not show a similar trend, with eight CSA / aFMM combinations resulting in an increment increase and seven in a decrease, while five indicate fluctuating and two stable volume increments.

Perhaps the most surprising result is the fact that there are only very small differences for the outcomes under the three frame scenarios. Given the substantial climatic changes, especially under the Reference scenario, and associated assortment price changes, especially under the Global Bioenergy scenario, the expectation was that the results would have been very different. The fact that this expectation did not materialize could be explained by several potential reasons. First, the forests may be able to adapt and mitigate against the climate change due to natural their resilience. Second, the management applied to them, including the introduction of the aFMMs, may allow for the adaptation of the management practices to the climate and market changes, resulting in similar levels of timber provision for 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 and increased the potential harvest volume in the Reference scenario (which included the largest temperature increase) and limited it (and the associated potential harvest volume increase) in the Global Bioenergy scenario.

As the climate aspect of the global frame scenarios assumes a gradual change, the strongest deviations from the current climate occur around the end of the 100-year forecasting period. So, in general, climate moves only slowly out of the tree species' comfort zone (if at all) in the analyses. In addition, some aFMMs even include tree species shifts in order to actively promote adapted species compositions. While climate change seems to be reasonably covered by the models as far as average annual climate characteristics are concerned, extreme events (e.g., pronounced droughts, fires, storms) are still problematic. The frequency and severity of such events might strongly increase in the future, which could potentially have a drastic impact on large forest areas. However, such effects are neither included in the global frame scenarios, nor are they readily implemented in silvicultural and management oriented forest growth models. This is subject to ongoing research.

Furthermore, it is also possible that the models and data used in the forecasting did not fully reflect the serious impact that the climate and market will have on the status and timber production capability of the forests in the future. One indication that enforces this possibility is the lack of a consistent increase in harvest volume in all CSAs in the Global Bioenergy scenario, which includes 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 is that wood production

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is an important means to climate mitigation and that timber will be an essential part of the bioeconomy if climate change is going to be kept small. This finding could indicate that for the stakeholders in each CSA, the production of other ESs 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, indicating that the Not In My Back Yard (NIMBY) approach overwrites the need for global solidarity and the sharing of the burdens of climate change mitigation. However, it could also indicate that the models did not sufficiently emphasise and enforce the global frame scenario conditions (i.e., substantial increases in assortment prices) on the analyses and the stakeholder considerations and behaviour.

Notwithstanding the potential limitations as discussed above, the results in all CSA / aFMM combinations indicate that sustainable wood production is maintained (except in cases where harvest is deliberately shut down as part of the concept, e.g., aFMM "Nature Conservation" 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 ESs, it appears that it may become very difficult to cover the future European and global timber demand, especially in the case where the Global Bioenergy scenario becomes reality.

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3.3 Regulatory Services

Ola Eriksson and José G. Borges

3.3.1 Introduction

The regulatory services that are assessed in this report exclusively relates to the capacity of management to mitigate risks. In some ESs taxonomies, like MEA, TEEB and CICES, other services are included in regulatory services as well. However, some of those are under other headings in this report, thus risk is the only a component that is analyzed here. Furthermore, by risk is meant risk for calamities, and not, for instance, uncertainty of what climate scenario will prevail or the impact of input data errors.

Ideally, you would analyze risk in terms of the potential or likely loss due to risk factors like wind throws, wild fire or pest outbreak. Ideally, this calculation would be done based on the configuration of landscape features, like edges at risk for wind throws, contiguous areas 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 do not exist. Even if you would have a reliable model, the calculation of the impact of a risk factor could become a daunting task, especially when risk refers to an entire landscape over a long time horizon, as is the case here. Thus, in many cases the risk assessment is based on expert judgement and classifications of risk rather than an empirically based risk assessment model. Spatial landscape analyses are also rare, i.e., risk assessments are based on the sum of stand characteristics or otherwise aggregate landscape measures without localized information.

3.3.2 Regulatory services assessed and assessment methods

Table 7 gives an overview of risks assessed in each CSA and a rough classification of the kind of method that have been used.

Table 7 Assessed risks

CSA and risk	Wind throws	Wild fire	Pest	Assessment method
Germany/AWF	X[1]		X[1]	Fuzzy logic
Germany/LST		X		Fuzzy logic
Ireland	X			Probability function
Italy		X		Qualitative reasoning
Lithuania[2]	X		X	Probability function
Netherlands	X	X		Value functions
Portugal		X		Classifier function
Slovakia	X[1]			Classifier function
Sweden	X			Qualitative reasoning
Turkey		X		Classifier function

[1] As significant bark beetle outbreaks (by most important pest in the CSA) usually occur in combination with wind throws and share similar risk factors, pest and wind throws are modeled as a combined risk.

[2] Mortality due to intra stand competition is also accounted for but not presented here, to ease comparison across cases. This risk is in several other cases built into the simulators and not presented as a regulatory service.

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Germany uses a fuzzy logic approach which involves literature and expert knowledge based rules and, based on this, mimics expert judgement of the risk for a calamity for each combination of the variables affecting the risk. The classification forms the basis for computing an average risk assessment for the landscape between 0 ("very low risk") and 1 ("very high risk").

Ireland and Lithuania have the same approach. They use logistic regression models that assig a probability to each stand in each simulation period. Ireland presents the consolidated result as the area above a certain probability threshold over the simulation period. Lithuania presents the landscape results as the average probability as well as the area in different vulnerability classes over the simulation period.

Portugal, Slovakia, and Turkey use the same approach in that they classify each stand in each simulation period into a vulnerability class based on the risk inducing factor. The value for each factor is then averaged over the landscape and finally weighted together into a landscape metric over the simulation period. The metric is also expressed as a classified value in five classes.

Netherlands apply a linear value function to each influencing factor. The function goes from best to worst and yields a value between 0 and 1 for each stand over the simulation period. The result is presented as a sum for each risk and consolidated as one risk index for both wind throws and wild fire over the simulation period.

Italy and Sweden apply the least formalized format. Both countries follow a qualitative reasoning about the development of risk influencing factors. Consequently, the results are presented as a qualitative statement on increase or decrease of risks associated with the global frame scenarios and the aFMMs.

In summary, Ireland and Lithuania, and Portugal use empirically based models. Germany, Slovakia, Turkey, and Netherlands use systems that rely more or less on expert input but translates into a numerical risk index (classification systems in which evaluations are more or less dependent on subjective inferences). Italy and Sweden leave it at qualitative evaluations. Italy and Sweden have data to connect to risk but do not attempt to quantify risk. None of the countries but Portugal has criteria that depend on spatial relationships; probabilities or indices are calculated on landscape quantities (in most cases computed as the sum over stands). Portugal use vulnerability probabilistic models that also depend on stand location and spatial configuration.

3.3.3 Results per CSA

In the following, the effects of aFMMs under different global frame scenarios are assessed. A positive correlation with increased risk of a factor is indicated with (+) and a negative correlation with (-). Only factors directly affected by management are recounted even though other factors are influential (e.g., site index, slope, soil moisture).

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Germany/AWF – Wind throw and subsequent beetle attacks

Risk related factors:

- The volume share of the risk species Norway spruce (+)
- The volume of large trees (i.e. trees with a dbh > 40 cm) per unit area (+)
- The species profile index (which is higher, the more rich in tree species and tree size structure forest stands are)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Multifunctional Nature conservation Production forest	Multifunctional Nature conservation Production forest	Multifunctional Nature conservation Production forest

The simulations reveal that there are only small differences between global frame scenarios, i.e. differences in risk refer to aFMMs. The highest risk is connected to the nature conservation aFMM, and stays constant or just slightly increases on a medium level. In contrast, the risk score of the multifunctional forest aFMM steadily decreases from medium down to low values. This is mostly connected with the decreasing share of Norway spruce with increasing species profile index. The risk associated with the production forest aFMM oscillates between low and medium scores and is due to consequences of an unbalanced age class distribution. Here, risk is increased by increasing shares of Norway spruce and decreasing mean stand diversity (species profile index), but decreased by early harvest which prevents large amounts of trees growing into risky sizes.

Germany/LST – Wild fire

Risk related factors:

- Scots pine volume share (+)
- Volume of trees with dbh > 30 cm (-)
- Share areas with understory (+)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Multifunctional Nature conservation Production forest	Multifunctional Nature conservation Production forest	Multifunctional Nature conservation Production forest

The simulations reveal that there are small differences between global frame scenarios, i.e., differences in risk refer to aFMMs. The highest risk scores are associated with the production forest aFMM due to the high and increasing volume shares of Scots pine and reduced shares of bigger trees (i.e. increasing numbers of small trees that more easily catch fire). In the first half of the simulation period

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nature conservation and the multifunctional forest have risk scores between medium and high values. After that the trend for the nature conservation aFMM is, contrary to multifunctional aFMM, decreasing risk due to an increase of trees with diameters greater than 30 cm. It should, however, be mentioned that the risk assessment of the local forest managers differed somewhat from this literature and practitioner-guideline driven assessment. They stated that their experience suggested that i) stand structural diversity decreased fire risk (while traditionally this would be seen as a risk factor, due to understory and subdominant trees acting as fire ladders), ii) deadwood was increasing fire risk significantly (which again was seriously doubted by nature protection representatives in the workshops), and iii) high shares of scots pine, regardless tree size, were equivalent with high fire risk. Therefore, an alternative fuzzy evaluation system was designed in order to also cover the local practitioners' view. The main difference compared to the original risk assessment was a switch of ranking between the multifunctional and the nature conservation forest. Due to the accumulating deadwood, the latter has higher risk scores than the former, while the production forest still is the most risky option due to the high share of scots pine and poor (mean) stand structure.

Ireland – Wind throw

Risk related factors:

- Top height (+)
- Thinned - 0/1 (+)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM set reported	Environmentally constrained profit maximisation	Environmentally constrained profit maximisation	Environmentally constrained profit maximisation

The simulations reveal that there are only small differences between the global frame scenarios as well as between aFMMs. The fellable (non-conservation) area with >75% risk of wind throws is doubled over the next 10 to 20 years, then steadily going down to very small areas after ca 50 years. The initial increase occurs as some fellable stands grow taller before being clearfelled. It can be noted that the aFMMs under Reference and EU Bioenergy are better than cFMM leading to a reduction of some 20% (>75% risk); the profiles for cFMM and aFMM are about the same under Global Bioenergy.

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Italy – Wild fire

Risk related factors:

- Thinning (-)
- Coppice (+)

	Global frame scenario		
	Reference	EU Bioenergy	Global Bioenergy
aFMMs eported	Recreational Production	Recreational Production	Recreational Production

There are no major differences between global frame scenarios. The thinning assumed in both the Recreational aFMM and in the Production aFMM reduces risk whereas the coppice in the Production aFMM increases risk. On the other hand, the Recreational aFMM is intended to attract more visitors, and this will very likely increase risk. It is also to be taken into account that in both aFMMs action against forest fires, such as reduction of undergrowth fuels, canopy raising, and reduction of density and continuity of the canopy will be implemented, following the indications of the Regional Fire Prevention Plan. This will help in keeping risks low.

Lithuania – Wind throws and pests

Risk related factors:

- Age of the stand (+)
- Diameter (-)
- Height (+)

	Global frame scenario		
	Reference	EU Bioenergy	Global Bioenergy
aFMMs reported	Economic rotation Financial rotation Deciduous forest Potential EU habitats	Economic rotation Financial rotation Deciduous forest Potential EU habitats	Economic rotation Financial rotation Deciduous forest Potential EU habitats

The differences between the global frame scenarios are not big, however there is a slight tendency that the Reference scenario results in lowest mortality probabilities, while the Global Bioenergy holds the largest ones. The probability of mortality due to wind and pests is decreasing during the whole simulation period. An exception is the Financial aFMM where the shorter rotations result in a jump up during the first 2 simulation decades; thereafter the same trajectory as for the other aFMM is followed. Even though all aFMM have a downhill trend risk there are differences. Potential EU habitats is associated with relatively larger mortality probabilities primarily due to relatively more aging of forests. The Economic aFMM result in smaller probabilities due to relatively larger share of

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younger stands (after 40 to 50 years Financial is on par with Economic). Deciduous forest falls in between for most of the simulation period. The development trends of mortality probabilities for wind throw and pest of applying aFMM are approximately following those of cFMM, however on a slightly lower level but for the Potential EU habitats aFMM.

Netherlands – Wind throws and wild fire

Risk related factors:

- Tree vulnerability/wind (+)
- Dominant height/wind (+)
- Stem number/wind (-)
- Tree vulnerability/ fire (+)
- Understory cover/fire (+)
- Tree size evenness on landscape level (+)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMMs reported	Reference gfdl Reference hdgem	Wood production	Bioenergy gfdl Bioenergy hdgem

The development of the compound regulatory services index over time depends on the combination of aFMM and global frame scenario, however the risk is small (+-5%) and even smaller if considering only the first 40 years. The stability is the result of a reduction of fire risk, first only slightly and after 2060 more (in total, >100% over the whole period), and an increase of wind risk first only slightly and after 2060 more (in total, 60% over the whole period). Both trends are the result of risk inducing factors getting affected by Dutch forests getting older, resulting in thicker trees, less tree density and a higher mortality. Note, though, that the results, especially in the longer term (> 40 years) should be interpreted with great caution due to modelling issues.

Portugal – Wildfire

Risk related factors:

- Tree density indicators (e.g., number of trees, basal area)
- Shrub biomass
- Age (years)
- Stand spatial configuration and context (e.g. relative position, edge shared)
- Precipitation, aspect

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	Scenario		
	Reference[1]	**EU Bioenergy**[1]	**Business as usual**[1]
aFMM vs cFMM	Stakeholder solution Max volume solution	Stakeholder solution Max volume solution	Stakeholder solution Max volume solution

[1] These are local scenarios – Global Bioenergy is not considered due to lack of data, instead there is a Business as usual scenario with no climate change.

The classification into vulnerability classes suggests that the increase of temperature and decrease of precipitation from the EU Bioenergy and Reference, compared with the Business as usual scenario, has a limited impact on the provision of regulatory services. For all three scenarios, vulnerability varies from class 3 (2026 and 2076) to class 4 only in the year 2026 and remains the same for the remaining years. The cFMMs have higher fire vulnerability than the aFMMs in the same period. This is associated with the periodicity of fuel treatments on the aFMM and cFMM selected prescriptions and the corresponding impact on the accumulation of fuel.

Slovakia – Wind throws and subsequent beetle attacks

Risk related factors:

- Proportion of Norway spruce of standing volume (+)
- Relative stand density (+)
- Number of tree species in the stand) (-)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM / aFMM set reported	Restitution of ownership Biodiversity Biodiversity & Restitution	Restitution of ownership Biodiversity Biodiversity & Restitution	Restitution of ownership Biodiversity Biodiversity & Restitution

The simulations reveal that there are only small differences between global frame scenarios as well as between aFMMs. The forest area with the lowest risk of windstorm and bark beetle damage is increasing over time. This is due to support for natural regeneration and reduction of spruce forests. The high drought sensitivity of spruce, the increased intensity and frequency of windstorms along with the better conditions for bark beetle reproduction pressures forest managers to replace spruce with other species. Comparing aFMM with cFMM, the former performs slightly better with regard to risk. The small differences between the aFMM and cFMM can partly be explained by a relatively large area of young forests in the focus area. The cFMM managed forest will be replaced by aFMM only after the rotation period is reached. Since the rotation periods are long (often over 100 years) the difference is small. Over a longer time period the aFMMs would show greater advantages compared to the cFMMs.

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Sweden – Wind throws

Risk related factors:

- Standing volume (+)
- Tree species diversity (-)
- Mean height (+)
- Thinning (+)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM set reported	Reference	EU Bioenergy	Global Bioenergy

The slack implicated by increased growth and relatively less demand under scenarios Reference and EU Bioenergy is used for enhancing biodiversity and deciduous species whereas growth enhancing measures to meet demand is implemented under the Global Bioenergy scenario. There is an increased risk for all aFMMs due to increased standing volume and increased average height of the forests. Global Bioenergy is also weighed down by a large share of coniferous forest. Compared to cFMM, risks are somewhat reduced with the Reference and EU Bioenergy scenarios in the aFMM due to more deciduous forest whereas risks are increased for the Global Bioenergy aFMM as a result of increased stocking level.

Turkey – Wild fire

Risk related factors:

- Basal area (+/- species dependent)
- Number of trees (+/- species dependent)
- Mean diameter (-)
- Crown closure (+)
- Age (years) in the case of even-aged stands (-)

	Global frame scenario		
	Reference	**EU Bioenergy**	**Global Bioenergy**
aFMM set reported	CCF	CCF	CCF

A reduction is registered of the consolidated vulnerability index over the simulation period due to lower vulnerability from a shift from younger stands over time to older and lower densities that compensates for slightly higher vulnerability from increased basal area. Thus, the risk class under all

global frame scenarios goes from high to medium vulnerability at present, and from medium to low vulnerability at the end of the simulation period.

3.3.4 Summary

Table 8 presents a summary statement of the risk levels embedded in the aFMM implementations under the different scenarios (risk level definitions in Table 9). The table is indicative and is only meant to give an overview of where risks appear to be a major problem due to the aFMMs. Since there is often a transition period from the current state to a future state formed by the aFMMs, the risk indicator is divided into the near future (ca 30 years) and the long term (100 years).

Table 8 Risk level indication in the medium term (ca 30 years) and the long term (100 years) for the different CSA under different global frame scenarios; in the case of 2 numbers, they show the interval between best and worst aFMM implementation under a global

CSA	**Risk**	**Medium term**			**Long term**		
		Ref	**EU**	**Global**	**Ref**	**EU**	**Global**
Germany/AWF	Wind throw	2-3	2-3	2-3	2-3	2-3	2-3
Germany/LST	Wild fire	3-4	3-4	3-4	3-5	3-5	3-5
Ireland	Wind throw	4	4	4	2	2	2
Italy	Wild fire	4	3	3	2	2	2
Lithuania	Wind throw	3-4	3-4	3-4	1	2	2
	Pest	3-4	3-4	3-4	1-2	2	2
Netherlands	Wind throw	2	2	2	4	4	4
	Fire	3	3	3	2	2	2
Portugal	Wild fire	2	3	3	2	2	3
Slovakia	Wind throw	4	4	4	2	2	2
Sweden	Wind throw	3	3	3	4	4	4
Turkey	Wild fire	4	3	4	2	2	2

Table 9 Risk classes

Class	**1**	**2**	**3**	**4**	**5**
Vulnerability	Low	Medium to low	Medium	High to medium	High

It is notable that in the long-term risks are expected to decrease or remain on the same level over time in most CSA. It is also notable that the more extreme climate change scenario Reference does not lead to higher risk levels than the more modest climate scenarios. This is to some extent a function of the fact that aFMMs are designed to promote sustainability, which in many cases has a positive effect on risks. There is, however, also a possibility that risks are underestimated due to limited knowledge of frequency and severity of future wind, drought and other hazards. The fact that none

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of the risk assessments explicitly accounts for this possibility makes it yet another point of precaution when interpreting the results.

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3.4 Carbon Sequestration

Kevin Black

3.4.1 Introduction

The contextual background to carbon sequestration is outlined in the introduction to section 3.4 of D3.2 (ALTERFOR WP3 leaders, 2018c). This is a summary analysis of the combined cFMMs and aFMMs and global frame scenarios using the carbon DSS. The assessment repeats the analysis done for D3.2, but also includes a detailed comparison of carbon sequestration under aFMMs, in particular:

- Investigate how traditional forest management indicators relate to forest C sequestration under different FMMs;
- Assess how different wood use policy scenarios may impact forest, HWP and product substitution C sequestration;
- Investigate the relationships and trade-offs between different FMMs and C sequestration.

3.4.2 Methodology

Carbon model

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). However, it is important to stress that the impacts of natural disturbances, such as fires, are not included in the ALTERFOR simulations. The risk of such impacts are interpreted in CSA reports where forest fires have a large impact on ecosystem GHG balance (e.g., Italy see ALTERFOR WP3 Leaders, 2018b and 2018c, section 3.4). Soils are another C pool that are not included in the C evaluation. Modelling of litter and soil C dynamics would require detailed inputs and calibration for each CSA which is beyond practicability in the context of ALTERFOR. However, the International Panel for Climate Change (IPCC) default for C stock changes in mineral soils is considered to be zero for managed forests (IPCC, 2006), so this assumption is adopted where relevant. In cases where there are organic soils within a CSA, such as study areas 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 be considered as part of the forest C balance (IPCC 2006). Organic soil emissions have not been included in the generic modelling framework provided to all CSAs. The emissions from organic soils are included in the DSS assessment for the CSA in Ireland, since most forest soils in this case are organic.

Scenario assumptions for each CSA

Detailed assumptions and potential climate change impacts under the different scenarios are discussed in detail under each CSA report (see MS12, ALTERFOR WP3 Leaders 2018b). The following table summarises the assumptions and climate change impacts included in the aFMM DSS under the three global frame scenarios for each CSA (Table 10).

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Table 10 A summary of imposed model effects/assumptions that may impact on the overall landscape C balance, including forest and HWP sinks and substitution effects (abbreviations of global frame scenarios: Ref = Reference, EU = EU Bioenergy, Global = Global Bioenergy)

CSA	Climate change impact	Impact on harvest allocation to HWPs	Impact on allocation to energy substitution	Impact on allocation to product substitution	Impact on overall harvest
Germany (both CSAs)	Yes, effect on productivity, species profile, disease and fire risk	Yes, distinct scenario differences; product inflow to HWP Ref > EU >Global	Yes, distinct scenario differences; energetic use Ref < EU < Global	Yes, distinct scenario differences; substitution Ref < EU < Global	Yes, depending on scenario. Also see change in sustainability index in CSA report (MS12)
Ireland	Yes, effect on productivity and species profile	Yes, increased allocation to HWP under Reference	Yes, higher energy substitution under EU and Global	No	Yes, slightly higher harvest under Global
Italy	Yes, but no fire disturbances are expected to occur under aFMMs	No	No, but all harvest allocated to sawlog or fuelwood	No	Yes, increase intensity of thinning under EU and Global
Lithuania	Yes, effect on productivity	No	Higher residue harvest for bioenergy under Global	No	Yes, decreased harvest under all, but higher pulpwood and residue harvest under EU and Global
Netherlands	No	Higher sawlog to WBP under Reference and EU	Lower harvest residue to energy under Ref and EU	No	No
Portugal[1]	Yes, higher yield increment in Ref and EU	Yes, higher pulp or saw log to WBP under EU or Global	Yes, higher saw log and pulpwood to energy under EU	Yes, higher saw log to products under Global	No
Slovakia	Yes, effect of productivity and species profile	Yes, higher pulpwood to WBP under Global	Yes, increase of 95% pulpwood and 50% harvest residue to energy in EU	Yes, slightly higher pulpwood to WBP under Global	Yes, higher harvest for all global frame scenarios
Sweden	Yes, effect on productivity, particularly in Ref and EU	No, but note high allocation of harvest to paper and pulp	No	No	Yes, increase in harvest under EU and Global
Turkey	No	Higher allocation to HWP under EU and Global	Higher allocation Ref<EU<Global	No	Yes, increase in harvest due to increased demand

[1] Based on R script outputs and previous reports

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PCA methodology

Principle component analysis (PCA) was used to investigate the impact of forest management and wood flow options, and their interactions, on C sequestration potential at the landscape level. PCA seeks to find linear relationships for combinations of factors such that the maximum variance is extracted from the factors. The variance of a factor (e.g., volume increment) is measured using an eigenvalue, which is the square root of the sum of squares (SS). If a factor has a low eigenvalue, then it is contributing little to the explanation of variances across the factors and may be ignored as redundant with more important factors. The analysis also provides information on the relationships between factors using eigenvectors for each principle component. This measures data in terms of its principal components rather than on a normal x-y axis. PCA provides a good method of evaluating and visualising trends in complex datasets where there are complex relationships between factors.

Trends between factors, such as outputs from the C sequestration evaluation tools and traditional forest management information were analysed in R studio using the general PCA and "ggfortify libraries". Normalisation of data is generally not required for PCA, but standardising factors (i.e. rescaling to a mean of 0 and a standard deviation of 1) was is required (Abdi and Beaton 2019). There are over 40 different outputs from the C sequestration tool at 10-year intervals over a simulation period 2020 to 2120. Inclusion of all outputs as factors in the PCA results in the identification of multiple principle components (PCs), which are difficult to analyse and visualise. Therefore, initial screening, categorisation and combination of outputs into more meaningful factors was carried out.

3.4.3 Results

C sequestration trends

Evaluation of C sequestration trends over time only considered the reference scenario based on the mean response for each CSA. Local scenarios (e.g., see Germany, Netherlands, Slovakia) are not considered in the analysis since they are covered in CSA reports in MS12. Temporal trends in forest and wood product sequestration were influenced by factors such as harvest level, volume increment, age class effects, variations in sustainability index and allocation of harvest to different end products (Table 11). Some CSAs describe climate change impacts on productivity, which would also influence forest C removals at the landscape level.

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Table 11 A summary of general temporal trends and identification of major drivers influencing C stock changes over time for the Reference scenario only for different CSAs (negative values represent a net emission (i.e. a source) and positive values indicate a net removal of CO_2, i.e., a sink)

Country	Forest sink trend[1]	HWP and substitution trend	Description of drivers	Mean total C stock change over period	Rank[2]
Germany Augsburg Western forests[3]	Local scenario dependent but production forests dominates the overall trend. Transition from source of ca -2tC/ha to a stable sink of 1tC/ha by 2060. A subsequent decline -0.4 tC/ha/yr to by 2110	HWP removals and avoidance emission due to energy replacement decline rapidly but stabilise by 2040	a) Forest C affected by increased harvests and sustainability indexes. b) HWP and energy substitution trends driven by level of harvest	1.1 tC/ha/yr	4
Germany Lieberose area	Dominated by productive forests. Initial decline in removals which stabilises by 2040	Increase in removals for 2030-2050 followed by period of stabilisation	a) Forest C driven by initial increase in sustainability ratios b) HWP and energy substitution trends driven by level of harvest	0.37 tC/ha/yr	8
Ireland	Decline from net removal (sink) to a net emission (source) over time series	Decline over period	a) Decline in volume increment due to younger age class transitions and negative climate change impact on species profile. b) Lower allocation of harvest to sawlog and long term HWP storage	-0.20 tC/ha/yr [4]	10
Italy	Increase from 0.2 in 2020 to over 1 tC/ha/yr by 2100	Slight increase	a) Increase in afforestation and reforestation areas b) Increasing volume increment c) Slight increase in wood product related to harvest	0.69 t/ha/yr [1]	7
Lithuania	Gradual decrease in removals over time, primarily under care for deciduous forest models	Increase in energy substitution emission reductions	a) A higher harvest form 2020 onwards b) Higher allocation of harvest to energy production	0.77 tC/ha/yr	6
Netherlands[3]	Slight increase over up to 2080 followed by a decline to 2100	Slight decline over period 2020-2100	a) Decrease in harvest and older forest structure. b) lower harvest results in lower HWP removals	2.06 tC/ha/yr	1
Portugal[5]	Extremely variable 2 to -2 tC/ha/yr	Slight increase in emission saving due to energy substitution	Trends largely driven by differences in productivity and harvest	0.97 tC/ha/yr [1]	5
Slovakia[3]	A general decline in removals up to 2070 followed by an increase	Slight decline in HWP products up to 2070. Increase in	a) Initial increase in harvest and decline in volume increment	0.28 tC/ha/yr	9

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	(depends on local scenario)	energy substitution from 2070	b) Higher allocation of harvest to energy substitution		
Sweden	Decline in removals to 2080 followed by an increase	Decrease in HWP storage, high allocation of harvest to paper (short term HWP storage)	a) Increase harvest and sustainability index c) High allocation of saw-log to paper	1.15 tC/ha/yr	2
Turkey	Large fluctuations but a general decline over the period to 2100	General increase in HWP and products	a) increased and harvest sustainability index	1.01 tC/ha/yr	3

[1] Excluding fire emissions for these CSAs (see Methodology).
[2] Scale from 1= highest C sequestration to 9 = lowest.
[3] Depends on local scenario (production, nature or multifunction). However, C sequestration trends are primarily associated with production forests.
[4] Including organic soil emissions.
[5] Based on R script outputs and previous reports.

Comparisons across different CSAs

Forest C

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. All factors were then initially included in the PCA, but factors and principle components (PCs) with low eigenvalues were excluded from the dataset to identify the most important factors. Selected forestry factors included, harvest volume (H), annual volume increment (VI), the ratio of harvest over annual increment (SI), share of broadleaves (BL), mortality volume (M) and harvest residue volume (HR). Forest C pools included aboveground (AB) and belowground biomass (BG), deadwood (DW) and the total annual forest C sequestration rates (Forest C).

The trends for forest C, HWP sequestration and product substitution emission avoidance were analysed separately. The number of PCs selected for further analysis was based on Scree plots and the Kaiser criteria which suggests that eigenvalues for each PC should be above one (Abdi and Beaton 2019). For each significant PC, factors with eigenvalues below 1 were considered to be redundant. PCA for forest C identified three significant PCs showing interrelationships between selected factors (Table 12 and Figure 19). The three PCs describe 81 % of the variance within the dataset. The sign of the factor eigenvalue indicates the direction of the vector (Table 12), different signs indicate opposing trends (inverse relationships). The magnitude of the eigenvalue indicates the relative importance of a factor within that PC.

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Table 12 Eigenvalues for significant PCs showing relationships between forest factors (the sign of the factor eigenvalue indicates the direction of the vector, different signs indicate opposing trends (inverse relationships), and the magnitude of the eigenvalue indicates the relative importance of a factor within that PC)

	PC1	PC2	PC3
Share of broadleaves (BL)	0.33	0.06	-0.35
Harvest (H)	-0.45	0.004	-0.05
Harvest/Increment (SI)	-0.39	0.03	-0.41
Mortality (M)	-0.15	-0.19	0.57
Volume increment (VI)	0.07	0.18	0.57
Harvest residue (HR)	-0.45	-0.11	-0.13
Aboveground C Stock (AG)	0.02	-0.61	-0.012
Belowground C Stock (BG)	0.06	-0.61	-0.03
Deadwood C Stock (DW)	-0.45	-0.13	0.13
Total Forest C balance (ForestC)	0.29	-0.36	-0.04
% Variance	**0.42**	**0.66**	**0.81**
Eigenvalue for PC	**4.24**	**2.31**	**1.48**

Trends can be more clearly visualised using PCA plots, which shows the vector size and direction and how categorical data is distributed with across PCs (Figure 19). This shows the distribution of CSA trends in relation to the eigenvectors. One can see that some expected relationships can be identified. For example, volume increment (VI) and mortality (M) vectors point in the complete opposite directions for PC2 (Figure 19). This suggests that these two factors are inversely correlated to each other. Vectors pointing in the same direction suggest that variables are closely related. For example, aboveground (AB) and belowground (BG) C pools are very closely related and the large eigenvalue suggest that the size of the biomass pools have a strong influence on initial forest C sequestration (Forest C), as expected. However, the analysis highlights some interesting trends. For example, the PCA plots suggest that forest C sequestration generally increases as level of harvest and SI decreases. This is particularly evident for PC1 (Figure 19 and Table 12) and consistent with observed trends summarised in Table 11.

The most striking observation is the clustering of CSA data within the PC plots (Figure 19). CSAs, such as Germany (DE) and Ireland (IE), with FMMs which have high levels of harvest and a high SI ratios and lower total C sequestration rates cluster together (Figure 19). In contrast, CSAs with FMMs which have a low level of harvest and low SI ratios have a high biomass stock and C sequestration rate (e.g., Netherlands CSA, (NL) Figure 19). It is also evident that CSAs with a high share of broadleaves (BL) are generally subjected to lower level of harvest and the similar eigenvalue of BL and Forest C suggests that C sequestration in forest is generally higher in FMMs with a high broadleaf share (for PC2 only, Table 12 and Figure 19).

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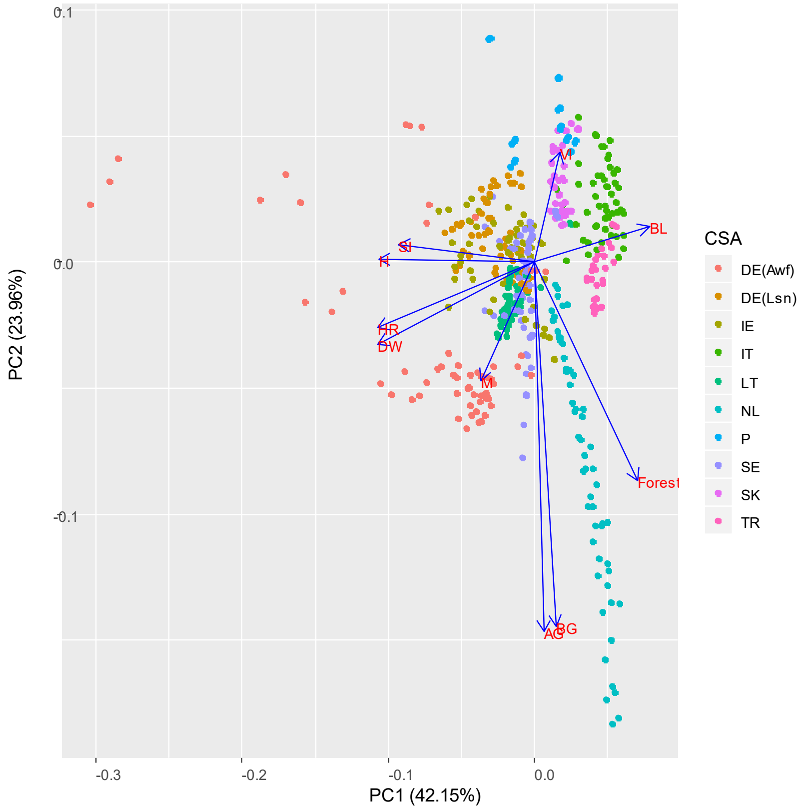

Figure 19 PCA using forest factors (red text) showing CSA specific trends. Abbreviations of factors: H= gross harvest, SI= sustaina-bility index (harvest/increment), VI = annual volume increment, BL= share of broadleaves, ForestC = net forest C balance, AG and BG= aboveground and belowground biomass stocks, M = mortality, DW= deadwood pool, HR= harvest residue left on site. CSA abbreviations: DE= Germany (2 CSAs), IE=Ireland, IT = Italy, LT= Lithuania, NL= Netherlands, P = Portugal, SE = Sweden, SK = Slovakia, TR = Turkey.

Wood flows and products

Factors for HWP sequestration and product substitution were combined into meaningful factors, in terms of product sequestration potential. For example, sawlog (CF_SWL) and WBP flows (CF_WBP) were combined into the two HWP categories. Energy and product substitution flows were combined into one factor (CF_PSubC). Initial analysis confirmed that eigenvalues for only PC 1 and 2 were significant, based on the Kaiser criteria (values > 1, Table 13). Therefore, PC3 trends are not considered in this case. For PC2, it is apparent that wood flows into energy or paper results in a lower HWP storage (Figure 20). For example, a large proportion of sawlogs and pulpwood harvest is used for paper in the Kronoberg and Vale do Sousa CSAs (SE and P, Figure 20) and these CSAs generally exhibit low levels of HWP sequestration. Similarly, a higher use of harvest for bioenergy production (e.g., the Italian CSA) results in lower HWP sequestration and emission avoidance product substitution, compared to CSAs where there is a higher flow into sawlog and WBP (e.g., Germany/AWF (DE/AWF) and Ireland (IE)).

The PC plots show that HWP sequestration increases as more wood is diverted into the sawn wood category (i.e., eigenvalues and vectors are similar for both PC1 and 2, Table 13 and Figure 20). This is expected because of the long-term C storage in sawn wood categories.

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Table 13 Eigenvalues for significant PCs showing relationships between HWP and product substitution factors (the sign of the factor eigenvalue indicates the direction of the vector, different signs indicate opposing trends (inverse relationships), and the magnitude of the eigenvalue indicates the relative importance of a factor within that PC)

	PC1	PC2	PC3
Process loss (CF_Ploss)	-0.46	0.04	Ns
Harvest to energy (CF_H_Ene)	-0.23	-0.54	Ns
Sawlog to sawnwood (CF_SWL)	-0.43	0.17	Ns
Harvest to WBP (CF_WBP)	-0.38	-0.08	Ns
Harvest to paper (CF_Pap)	-0.03	0.81	Ns
Total HWP C	-0.41	0.11	Ns
Total product substitution	-0.47	-0.02	Ns
% Variance	**0.56**	**0.77**	**0.91**
Eigenvalue for PC	**2.43**	**1.12**	**0.77**

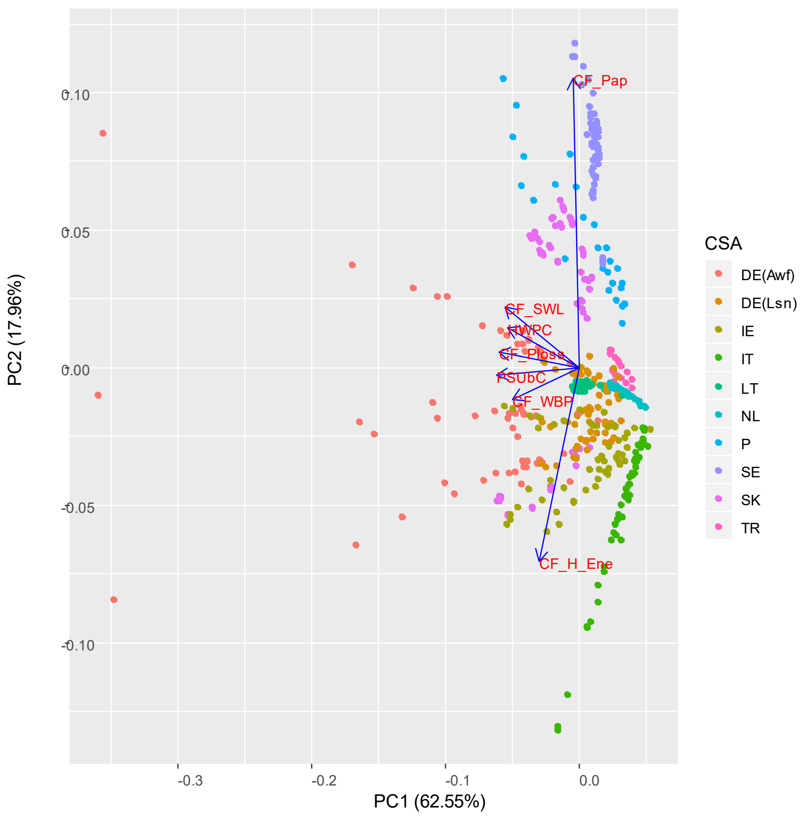

Figure 20 PCA using forest factors (red text) showing global frame scenario specific trends. Abbreviations of factors: CF_pap = carbon flow into paper, CF_SWL= carbon flow into sawn wood, CF_WBP = carbon flow into WBP, CF_H_Ene. = carbon flow into bioenergy, CF_Ploss = process losses during timber manufacture, HWP_C = total HWP sequestration and PsubC = emission avoidance through product substitution. CSA abbreviations: DE= Germany (2CSAs), IE=Ireland, IT = Italy, LT= Lithuania, NL= Netherlands, P = Portugal, SE = Sweden, SK = Slovakia, TR = Turkey.

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Comparisons across different global frame scenarios

There were differences in the C sequestration for forest C sinks, HWP and substitution across the three global frame scenarios, but the magnitude and relative difference in the total C sequestration rate varies for different CSAs. Table 14 identifies the best C sequestration scenario within specific CSAs (highest ranking scenario) and summarizes potential reasons for the differences between global frame scenarios within each CSA.

Table 14 Summary of comparison of global frame scenarios across CSAs

Country	Description of differences between global frame scenarios relative to the Reference scenario in specific CSA	Highest ranking global frame scenario
Germany Augsburg Western forests	EU Bioenergy: a) Highest forest sink, consistent with higher sustainable wood production and higher volume increments relative to other scenarios b) More HWP storage and emission saving due to energy substitution associated with a higher sustained harvest and allocation to wood products Global Bioenergy: a) Lowest forest C sink due to lowest productivity associated with negative climate change impacts and change in species profile towards beech. Accumulation of C in DOM pool decreased due to high allocation of harvest residues to energy production b) Lowest sawlog harvest and hence lower HWP sink c) Lower energy substitution due to less harvest and despite higher allocation of harvest residues to energy production	EU Bioenergy
Germany Lieberose area	No clear differences	EU Bioenergy
Ireland	(Small differences) EU Bioenergy and Global Bioenergy marginally lower than Reference: a) The EU Bioenergy and Global Bioenergy scenarios utilised more pulpwood for biofuels, rather than mainly utilising it for wood panel boards, whereas the Reference scenario mainly utilise pulpwood for wood panel board.	Reference
Italy	(Small differences): a) Higher harvest and allocation to energy use in Global Bioenergy scenario	Global Bioenergy
Lithuania	(Small differences): a) Higher harvest residue allocation to energy under Global Bioenergy and EU Bioenergy scenarios. b) Smaller climate change impacts	Reference
Netherlands	EU Bioenergy higher than Global Bioenergy and Reference 1. Higher forest C sequestration due to higher volume increment and lower sustainability ratio 2. EU Bioenergy has higher allocation of wood product to long term storage that Global Bioenergy	EU Bioenergy
Portugal	No differences, trends largely driven by forest C balance	Reference
Slovakia	EU Bioenergy higher than Global Bioenergy, both higher than Reference: a) Higher harvest volume and proportion of timber products to HWP and product substitution under Global Bioenergy. EU Bioenergy shows a very high share of harvest to energy substitution b) Global Bioenergy and EU Bioenergy show larger positive impacts of climate change on volume increment and higher forest C removals, compared to Reference scenario	Global Bioenergy
Sweden	EU Bioenergy higher than Global Bioenergy, but both lower than Reference: a) Higher harvest under EU Bioenergy and Global Bioenergy scenarios results in a larger decline in the forest sink, which is not offset by allocation of harvest to HWP because of high proportion of wood allocated to short term HWP products (paper)	Reference
Turkey	(Small differences) 1. Higher forest C sink under Global Bioenergy scenario	Global Bioenergy

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Forest C

A PCA plot of the 3 different global frame scenarios suggest that there are no clear clustering pattern or trends (Figure 21). This suggests that the global frame scenarios may have an overall small impact on C sequestration and timber services, but variations with in CSA can be expected. For example, the impact of climate change may be greater under different global frame scenarios. This might in turn have positive or negative impacts on forest C sequestration.

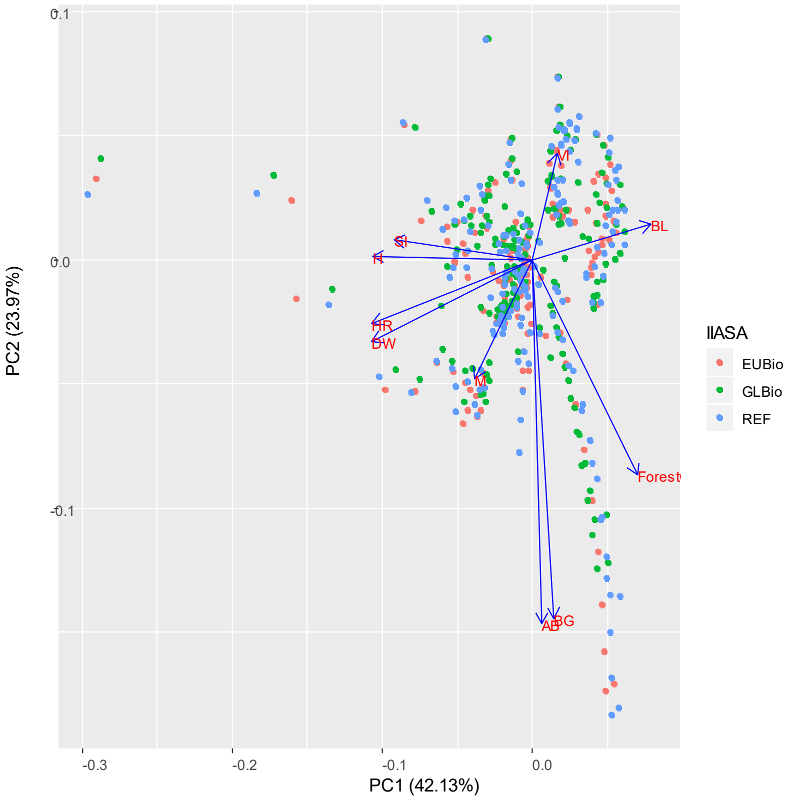

Figure 21 Forest factors (red text) PCA showing global frame scenario responses. Abbreviations of factors: H= gross harvest, SI= sustainability index (harvest/increment), VI = annual volume increment, BL= share of broadleaves, ForestC = net forest C balance, AG and BG= aboveground and belowground biomass stocks, M = mortality, DW= deadwood pool, HR= harvest residue left on site.

Wood flows and products

A PCA for different global frame scenarios suggests that more harvest is allocated to energy substitution under the EU and Global Bioenergy scenario (PC2, Table 11 and Figure 22) resulting on a lower HWP sequestration and emission avoidance product substitution, when compared to the Reference scenario. This trend is, however, not consistent in the Kronoberg and Vale do Sousa CSAs (SE, P, Figures 20 and 22), because most harvest is allocated to paper production.

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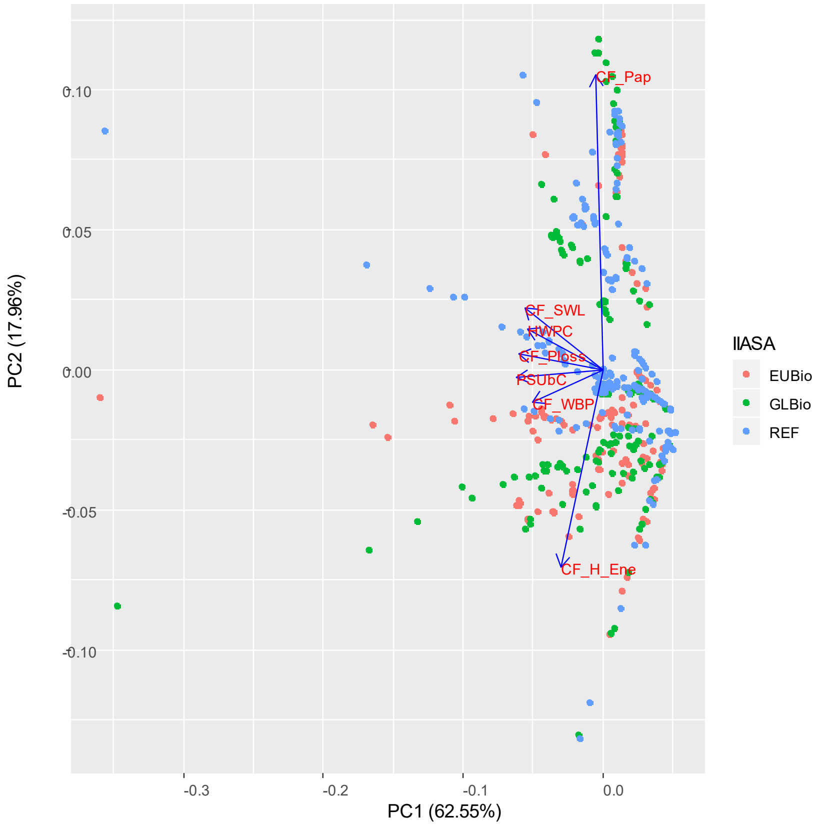

Figure 22 PCA using forest factors (red text) showing global frame scenario specific trends. Abbreviations of factors: CF_pap = carbon flow into paper, CF_SWL= carbon flow into sawn wood, CF_WBP = carbon flow into WBP, CF_H_Ene. = carbon flow into bioenergy, CF_ Ploss = process losses during timber manufacture, HWP_C = total HWP sequestration and PsubC = emission avoidance through product substitution.

Interactions between forest and wood product sequestration

Figure 23 shows a summary of a PCA for the three primary C sequestration components, i.e., Forest C, HWP and emission avoidance through product and energy substitution. The analysis confirms the working hypothesis that sequestration in forests and through wood utilisation paths is opposed (i.e., inversely related for PC1). The result, however, also suggests that overall sequestration may be maximised if sequestration in the forest is prioritised since the eigenvectors for total and forest C are in the same direction for PC 1. However, it is also apparent from PC2 that both wood utilisation and Forest C paths both contribute to total C storage (Figure 23). There are also clear CSA trends, due to interactions discussed above for HWP and forest C PCA results. For example, CSAs in Germany, Ireland and Slovakia have higher overall sequestration contributions through HWP and product substitution and a lower over forest sequestration contribution.

Comparison of aFMMs within CSAs clearly demonstrate the trade-off between forest C, product and total C sequestration. For the Augsburg Western Forests (Germany), the Production forest aFMM shows ca. 4 times lower forest C sequestration, when compared to Multifunctional and Nature conservation aFMMs. However, the overall C sequestration of Production forest is only ca 32% lower than the Multifuctional and Nature conservation aFMMs.

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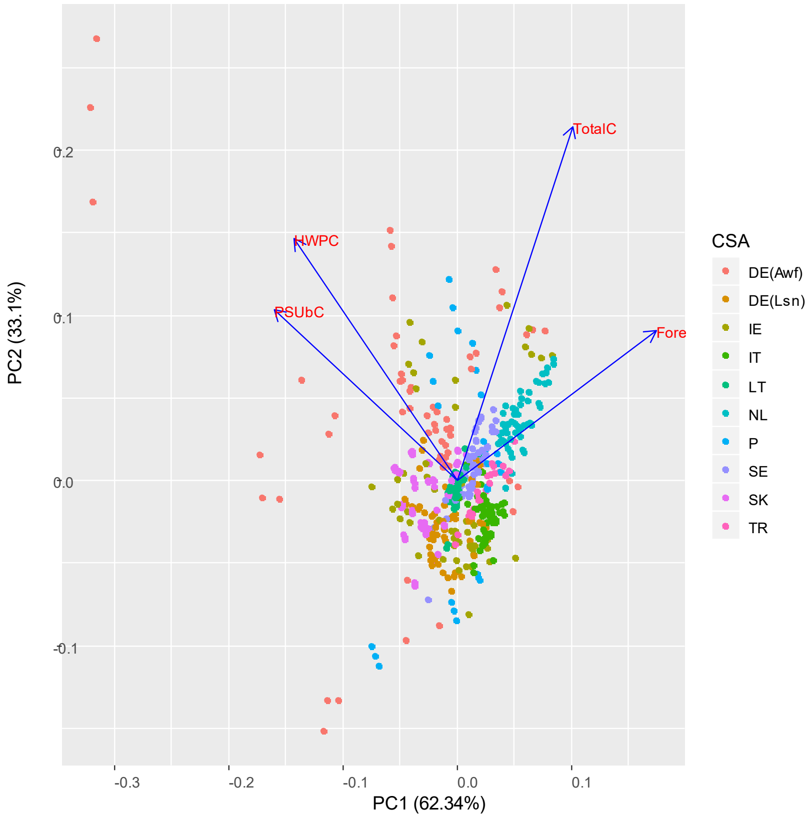

Figure 23 A PCA plot showing trends between C sequestration components: ForestC= total forest sequestration, HWPC = harvested wood product sequestration, PSubC = emission avoidance due to product substitution and the total (total C) sequestration.

For the Italian CSA, uniform shelterwood and coppice FMMs produce 32% more timber, compared to close to nature FMMs (i.e., Recreational and habitat selective cutting (aFMM1)). Although forest C sequestration is lower for the shelterwood and coppice system, this is off-set by a higher inflow of wood product to emission avoidance by energy substitution. These results suggest that sequestration potential of intensively managed or plantation forests may be underestimated if HWP and product substitution in not included in the model system boundary.

Comparison of current and alternative FMMs

Comparison of DSS outputs from cFMM and aFMMs for some CSAs should be interpreted with caution since different modelling approached were adopted for the two analyses. Some CSAs (e.g., Ireland and Sweden) reran the DSS model for the different cFMMs, to make comparisons valid.

Overall C sequestration potential varied for different FMMs depending on the CSA and global frame scenario (Figure 24). In some CSAs (e.g., Ireland, Slovakia, Germany/LST), Lithuania) cFMMs provide a higher C sequestration potential when compared to aFMMs across all global frame scenarios. The Irish aFMM was designed to address water quality directives which required deforestation and planting of less productive species resulting in a lower C sequestration. In Polana (Slovakia) the harvest was ca. 30% higher (average for all global frame scenarios) under aFMMs, when compared to cFMM. This may have been driven by an increase in the freedom of decision-making in forest management

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and, in the case of small forest owners, improvement the flow of timber and income. The forest C sequestration for Polana under the aFMMs were 2 to 10 times lower than under cFMM. The Lithuanian CSA also reported higher harvest and a lower forest C sink under the aFMMs. This also appeared to be related to introduction of adaptive rotation ages under the aFMMs.

Other CSAs showed the opposite trend, where aFMMs provided an improved C sequestration potential relative to the cFMMs, across all global frame scenarios (e.g., Sweden, Portugal, Italy and Turkey). For the Kronoberg (Sweden), and AFP (Italy) CSAs, the aFMMs favour other ESs over timber production. This resulted in lower forest C sequestration for cFMMs, when compared to aFMMs. In Italy, one aFMM was proposed to specifically reduce risk of forest fire. This would have a positive C sequestration impact, albeit that fire emissions are not included in the carbon DSS. The results showed that aFMMs amounted to higher C stocks in the Gölcük CSA (Turkey), which appear to be related to the introduction of continuous cover forestry (CCF). It is suggested that there was an increase in standing volume within the forest via age class shifts, replacing degraded and sparsely distributed stands with productive stands as well as an increase in forest productivity and an increase in the harvest to increment ratio overtime.

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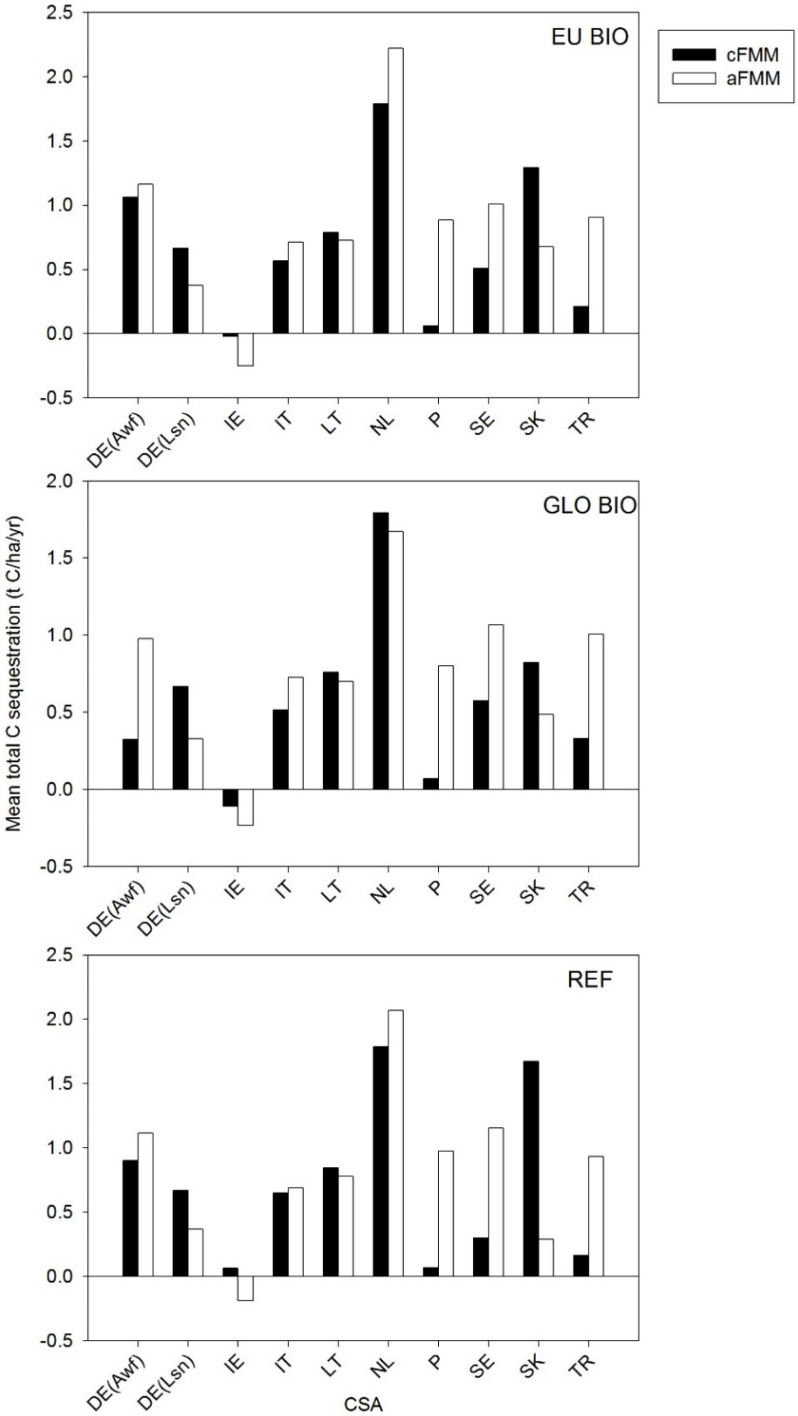

Figure 24 Comparison of cFMM and aFMM mean C sequestration rates for CSAs under the three global frame scenarios.

3.4.4 Conclusions

In summary, temporal trends in the forest C sink for many CSAs appear to be closely related to variations in either the level of harvest or changes in productivity (or both, i.e., sustainability index). Forest C sink trends can be closely correlated with sustainable productivity indices (SI). Changes in volume increment can also have a large impact on the forest sink and supply of timber for HWP at

the landscape level and this appears to be driven by climate change impacts (Hanewinkel et al., 2013) or by shifts in the forest age class structure (e.g., Ireland and Turkey; Böttcher et al., 2008).

PCA of forest C and timber production outputs from the DSS suggest clustering of CSAs with different management strategies varying from low impact to intensive plantation forestry. CSAs with aFMMs characterized by high rates of harvest and sustainability indices generally exhibit low forest C sequestration rates. In contrast, low impact systems with a low level of harvest and low sustainability indices 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. In addition, buildup of deadwood C stocks may present a higher fire risk (Vilén and Fernandes, 2011) and very large disturbance emissions, which are not factored in into the DSS.

PCA analysis on HWP and product substitution sequestration confirm findings from D3.2 (ALTERFOR WP3 Leaders, 2018c), that higher wood flow sequestration rates are associated with CSA clusters that have high harvest levels and large allocations to long term storage products. Inflow of wood for energy use or paper generally results in lower product sequestration. These trends are also consistent across the three global frame scenarios, where in most cases there is a higher bioenergy demand under the EU Bioenergy and Global Bioenergy scenarios.

This study highlights the importance of evaluating the complete C life cycle, and not just forest C stocks, under different scenarios. It is evident in some cases (e.g., the German aFMM Production forest) that the forest 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 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 is not offset by HWP storage because of the small expected C half-life of pulp and paper products.

The Nature conservation aFMM in the Augsberg Western forests (Germany) represents an interesting case because it offers no HWP or product substitution potential and it is observed that the forest C removal decrease over time as stand reach the maximum growth rate. Although old growth forests are considered to act as small C sinks (Luyssaert et al., 2008), results from the German CSA may suggest that 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.

There are no clear trends to suggest that the new proposed aFMMs may result in a higher C sequestration potential when compared to the cFMMs in CSAs. This is perhaps not surprising since some aFMMs were adopted to specifically address other ecosystem needs. Generally, aFMMs which adopted low impact management or a reduction in harvest to meet other ESs resulted in a higher C sequestration potential. The results for the CCF managed forest in Turkey (aFMMs) resulted in a large increase in C sequestration potential when compared to the cFMMs. These findings contrast with other studies, (e.g., Lundmark et al., 2016) which show that C sequestration is not different for CCF versus conventional plantation forest management. However, the study by Lundmark et al. (2016) was done using a stand-based model. In contrast to landscape models, stand models do not consider

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the effect of shifts in age class structure in the landscape and how this may impact on overall C balance. Introduction of a CCF system in the Gölcük CSA did result in a shift in age class structure, where regeneration and volume increment increase, relative to cFFMs.

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3.5 Water Related Ecosystem Services

Davide Zoccatelli and Marco Borga

The aFMMs proposed by the case studies reflect possible managements for the area. Most aFMMs identify a general management direction, trying to assess the effects on the pool of ES. However, some of them aim at maximizing particular ES – such as the Italian recreational and habitat selective management, or the German Nature conservation aFMM or the Lithuanian Potential EU habitats. Water related ES are never explicitly the main management objective of the scenarios, but can play an important role in cases such as Ireland, Slovakia or Turkey.

Each LCC selected the water-related ES and the approach that was most relevant for their CSA. This lead to a number of approaches and services examined. The most recurrent ESs are water chemical conditions and erosion control, often joined under water quality. These ESs were included by eight CSAs out of nine, some in support of biodiversity (Ireland, Italy), or in relation with the release of specific chemical component (Sweden), with a stronger focus on erosion (Portugal), or in relation to drinking water (Turkey, Slovakia). Other areas focused also on water yield (Turkey) or water flow maintenance (Germany). Two case studies, the Netherlands and Slovakia, analysed the impact of aFMMs on a wide range of water-related ES.

Table 15 summarizes the approaches used and the ESs examined for each CSA. In five cases the variation in water-related ESs was analysed using DSS outputs, as suggested in the basic approach of the guidelines. Most of them applied the approach schematically, with scores for each element, while a more descriptive analysis was used in a few CSAs. In four CSAs an external model was used to quantify the variation of specific ES provision. These models range from literature evaluations of different managements, to water-related indexes, or mathematical models. In the case of Germany, empirical relations between groundwater recharge and forest management were identified and integrated into the DSS model. This allowed to include groundwater recharge in the model outputs, and easy to quantitatively compare the scenarios.

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Table 15 Summary of the approaches and outputs for water related ES in each country

Country	Approach	Result type	ES analysed	Drivers description
Germany	DSS model	Indicator quantification	Flow maintenance	Species composition, stand density, site conditions
Ireland	External model	Indicator quantification	Water quality	Felling area, landscape composition
Italy	DSS outputs	Direction of change	Erosion contr.	Forest age, tourist pressure, harvest volume
Lithuania	External model	Grade quantification	Erosion contr.	Share of spruce, stand age
Netherlands	DSS outputs	Direction of change	5 water ES	Forest age, harvest volume
Portugal	External model	Indicator quantification	Erosion contr.	Species composition, thinnings, precipitation
Slovakia	DSS outputs	Direction of change	Water yield Erosion contr.	Harvest volume, age, rotation length
Sweden	DSS outputs	Indicator quantification	Water quality	Felling area, Wood degradation (DOC)
Turkey	External model and DSS output	Indicator quantification, direction of change	Water yield Erosion contr. Ch. conditions	Stand age, harvest volume, basal area

In Table 16, a summary of the trends identified for all aFMMs is presented. The trends on different ES provision from aFMMs relative to the current forest situation are assessed for all CSAs. When possible, the trend in different ES provision from aFMMs are also compared with future conditions under the cFMMs. (The cFMMs are not comparable with aFMMs in all CSAs since significant model development have taken place in some CSAs since the cFMMs were projected.) Even if the trends are not homogeneous across CSA, we think that this comparison is useful to highlight the importance of the aFMMs in delivering the ESs. A clear case is the Netherlands, where water-related ES are expected to increase with aFMM relative to current conditions regardless of global frame scenario, and the comparison with the cFMM helps to highlight the effect of the aFMM.

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Table 16 List of aFMMs, their objectives and the effect on water-related ES; the trends are relative to current forest conditions and future conditions under cFMMs and can be positive (+), negative (-) or null (=) (abbreviations of global frame scenarios: Ref = Reference, EU = EU Bioenergy, Global = Global Bioenergy)

Country	**Main objectives of the aFMM**	**Water-related ES**	**Trend relative to current conditions**			**Trend relative to cFMM**		
			Ref	**EU**	**Global**	**Ref**	**EU**	**Global**
Germany	Multifunctional	Flow maintenance	=	=	=			
	Production	Flow maintenance	-	-	-			
	Nature conservation	Flow maintenance	=/-	=/-	=/-			
Ireland	-	Water quality	=	=	=	=	=	=
Italy	Recreational and habitat selective	Erosion control	-	-	-			
	Uniform shelterwood and coppice	Erosion control	-	-	-			
Lithuania	Adaptive rotation ages	Erosion control	-	-	-	=	=	=
	Care for deciduous	Erosion control	=	=	=	+	+	+
	No management in potential habitats of EU importance	Erosion control	-	-	-	=	=	=
Netherlands	-	5 ES	+	+	+	=	-	-
Portugal	Low density pine	Erosion control	-	-	-	=	=	=
	Short rotation oak	Erosion control	+	+	+	+	+	+
	Cork oak	Erosion control	=	=	=	+	+	+
Turkey	Continuous cover forestry	Water yield	=/-	=/-	-			
		Erosion control	=	+	=/+			
Slovakia	Partly uneven-aged mixed stand	4 ES	=	=	=			
	Even age mixed stand	4 ES	-	-	-			
Sweden	Multiple adaptations to global frame scenarios	Water quality	=	=	-			
Turkey	Continuous cover forestry	Water yield	=/-	=/-	-			
		Erosion control	=	+	=/+			

The trends reported in Table 16 provides a summary of the relation between the main management objectives of different CSAs and their effect on water ES. Overall, trends across Europe seem to be rather complex. The main impacts of forest management seem often to be related with harvesting intensity and rotation length. In some case, such as Germany, Sweden, Italy or Slovakia, there seems to be a conflict between timber production and water ES. In many cases, water quality or erosion control is critical right after felling and the effect persist for multiple years. Other interesting contrasts between erosion risk and the provision of different ES are identified for Italy and Portugal. In

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Italy, the conflict is with tourist activity, and when tourism is the main management objective it can lead to localized erosion. In Portugal, the conflict is with fire risk reduction, where the lower forest density required to reduce fire risk leaves the soil more exposed to erosion.

Finally, the differences in the results for the three global frame scenarios are mostly not substantial; however, there are exceptions. The global frame scenarios have an impact in areas where they lead to significant differences in harvesting intensity and rotation length, such as Sweden and, to a minor extent, Germany. However, it is interesting to see the effects of the amount of precipitation when this has been incorporated in the analysis, like in Germany and Portugal. When change in precipitation and potentially temperature, is included, it has a significant effect on water-related ESs such as erosion rate and groundwater infiltration. This is related with changes in the total amount of precipitation, its seasonality and the frequency of extreme events.

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3.6 Cultural Services

Marjanke Hoogstra-Klein and Geerten Hengeveld

3.6.1 Background on the calculations

For most of the CSAs, the Recreational and Aesthetic value of Forested Landscapes (RAFL) index as developed within the ALTERFOR project was used again, with a case specific operationalisation of the concepts (see individual case descriptions in MS12 for detailed information (ALTERFOR WP3 Leaders, 2018c)). Like in the previous round of analyses of the RAFL (for cFMMs), some countries took a different approach. Germany used their own fuzzy logic system tailored to some of the key variables available in their DSS. Lithuania made use of different individual attributes provided in the RAFL index. Sweden chose to focus on a selection of the concepts and dimensions of the RAFL index.

The evaluation of aFMMs was also somewhat different in the different case study areas. Some of the countries focused on the evaluation of specific aFMMs. Germany, for example, contrasted extreme versions of the three currently most debated competing forest management approaches: multifunctional forest, nature conservation forest and production forest. Italy compared two different aFMMs: a recreational and habitat selective management model and uniform shelterwood and coppice. Lithuania analysed four different aFMMs: adaptive rotations (economic), adaptive rotations (financial), care for deciduous forest and no management of potential habitats of European importance. Turkey analysed the introduction of one aFMM (Continuous Cover Forestry) to replace one of the eight cFMMs. The other countries linked the aFMM(s) to specific owner types, implicating that different combinations of aFMMs were analysed, depending on the global frame scenario involved.

As regards the scenario analyses, all case studies included the three basic global frame scenarios (Reference, EU Bioenergy, and Global Bioenergy), except for the Portuguese case where related locally calculated climate scenario projections were used. In some cases, additional scenarios were included to cover case specific developments. Slovakia, for example, included the area of unmanaged forests and the restitution process as variables in the scenarios, leading to 12 scenarios. The Netherlands included a Business-as-Usual scenario (as Ireland also did, having four scenarios analysed), but also developed different climate scenarios and one socio-economic scenario, leading to in total eight scenarios for the Dutch case.

3.6.2 Comparison of aFMM(s) with current forest management

As regards the scores of the aFMMs in comparison to current forest management, as far as the data were available, results show that:

- the introduction of (a) new aFMM(s) can lead to both higher and lower recreational values,
- the improvement is in some of the CSAs frame scenario independent, i.e., a low scenario sensitivity exists or differences are very small.

Slovakia, Portugal and Ireland, for example, observed an improvement (but in some cases a rather small improvement) in the overall recreational value when introducing new aFMMs, which was almost similar for all global frame scenarios. In Italy, both aFMMs perform better than the cFMM under all global frame scenarios.

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In contrast to the other countries, in Sweden and Germany the results are scenario specific. In Sweden, the recreational value would profit from the introduction of the aFMM under the Reference and EU Bioenergy scenarios but suffer in the Global Bioenergy. Differences exist between the scores in the Global Bioenergy scenario on the one hand, and the EU Bioenergy and the Reference scenario on the other hand.

In the German Augsburg Western Forest CSA, the aFMM Multifunctional management scores much better than current management in all global frame scenarios. The area would only profit from the introduction of the aFMM Nature conservation management in the Reference scenario. In all other cases, no improvement or even a deterioration of the recreational value occurs. In the German Lieberose Schlaubetal area, Multifunctional forest management and Nature conservation management bring (small to considerable) improvements in the Global Bioenergy and the EU Bioenergy scenarios, but not in the Reference scenario. Production forest does not make much of a difference or leads to a slight deterioration in all global frame scenarios.

The effect of introducing different aFMMs in the Netherlands could only be evaluated for the Business-As-Usual (BAU) scenario (due to difficulties in the scenario analyses for current forest management), and only on the short term (due to modelling issues). The outcome is, however, not so positive: a relatively drastic decrease in the recreational value is to be observed in the first decades with the introduction of aFMMs, which is in sharp contrast to a positive development of the recreational value for current management.

In Lithuania, the introduction of alternative aFMMs would lead to mixed results; some attributes profit from the introduction of a specific aFMM, others do not.

3.6.3 Development of the recreational value of aFMMs

The developments of the recreational values over time reflect different patterns in the different CSAs. In Portugal, for example, the RAFL index remains rather stable over time in all local scenarios. Slovakia's RAFL reflects a completely different pattern: in all sub-scenarios the recreational value increases up to 2040, remains rather stable from 2040 until 2070/2080, and decreases again to a score that is only slightly better that the starting value. The Reference scenario scores best in the first decades, but after 2070/2080 the EU Bioenergy scores better. In all cases, the Global Bioenergy scenario scores lowest. In Ireland, in all scenarios the increase of the recreational value is more continuous, but with two smaller troughs around 2040 and 2090. Italy also shows a more continuous increase of the recreational value in the scenarios, with the recreational and habitat selective management model receiving higher scores than the uniform shelterwood and coppice model. This is not that surprising as the recreational and habitat selective management model is explicitly focused on increasing the recreational value of the forests in the area. For Sweden and Lithuania, it is more difficult to determine the overall development of the recreational value of the aFMMs as no overall score is provided. The different concepts analysed in Sweden reflect mostly positive developments, but in some cases also very erratic ones. Scores for all attributes are higher in the Reference and EU Bioenergy scenarios than in the Global Bioenergy scenario. The developments of the different attributes in Lithuania also hint at a more fluctuating approach, which is in contrast overall essentially negative.

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In Turkey, the developments are also scenario specific. In all global frame scenarios, the recreational value decreases in the first decades, but increases again after 2055 in the Reference scenario, whereas the values remain stable/decrease a little in the two other scenarios after 2055.

In the two German cases, the (development of the) recreational values depend on both the aFMM analysed and the global frame scenario involved. In the Augsburg Western Forests, Multifunctional forest management scores better than Nature conservation, which in turn is overall better than the Production forest. Nature conservation is the most stable over time, with almost no change in value, whereas the recreational values of the Multifunctional forest management increase in the order Reference, EU Bioenergy, and Global Bioenergy. The Production forest value is the most fluctuating over time, although in the same order as for the scenarios in Multifunctional forest management, the level increases and the oscillation decreases. As regards the Lieberose Schlaubetal area, in all global frame scenarios the Production forest scores the lowest of the three management approaches, but while in the Reference scenario Nature conservation scores best, the Multifunctional forest scores best in the Global Bioenergy scenario. Most of the values show somewhat fluctuating scores, with the Multifunctional forest management in the EU Bioenergy scenarios having the most stable score over time.

In the Netherlands, where the development can only be evaluated up to 2040, first a sharp decrease is observed - up to 2020, after which the value increases again.

3.6.4 Major factors influencing the recreational value of aFMMs

When analysing the developments of the recreational values in all CSAs, one can carefully conclude that harvesting activities are a major source influencing the development of the recreational value. In Slovakia, for example, the fluctuations are mostly the result of the stewardship score and, to a somewhat lesser extent, the visual scale, which are both determined by the amount of harvesting taking place. In the first decades, forests get older and less harvesting takes place (leading to less harvesting residues), resulting in an increase in the recreational value. This changes in 2040, when remaining stands are harvested (with more harvesting residues as a result) and regeneration takes place (leading to a decrease in visual scale). From 2070 on, more harvesting takes place due to the higher market demand. In Ireland, the two troughs can be linked to two harvesting peaks. The negative developments of aFMMs in Lithuania are also mainly the outcome of harvesting activities, as is the case in the Netherlands where much harvesting takes place in the first years, leading to large amounts of harvesting residues (and hence a low stewardship score). Italy also observed that the presence of intense logging activities (in this case coppicing) negatively affects the recreational values; the recreational and habitat selective management model receive higher scores than the uniform shelterwood and coppice model.

For Sweden and Germany, somewhat different factors (also) seem to play a role. In the German cases, the reason for differences can in part be assigned to harvesting activities, which is, for example, reflected in the oscillating pattern for the Production forest linked to phases of intensive harvest with high harvest amounts and large amounts of harvest residues in the Augsburg case. However, next to that the different treatments of the harvest residues in the three global frame scenarios play an important role: in the Reference scenarios almost all harvest residues remain in the forest (which is negative to the recreational value), whereas in the Global Bioenergy scenario most of these residues are taken out for energetic use; the EU Bioenergy scenario is in between. In Sweden, increased

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final felling and shorter rotations are also implicated as a driving factors, but differences in scores are also attributable to a decrease in species diversity and the reduction in deciduous forests, related to the increasing market demand.

In Portugal, where the RAFL index remains rather stable over time, the different concepts' scores also remain rather stable.

3.6.5 Best scoring concepts and dimensions in the CSAs

As regards the concepts or dimensions scoring best in the different CSAs, this is very CSA specific. In Slovakia, Turkey, Portugal and the Netherlands, ephemera is always at maximum, due to the high volume of broadleaves present, in all global frame scenarios. In Italy, stewardship is at a maximum in both aFMMs in all scenarios. This is the result of harvest residues being removed in both aFMMs. In Ireland, the visual scale scores highest, which is the result of the aFMMs allowing for low-stocking reforestation of lodgepole pine, affecting the openness dimension.

In Sweden and the German case, the situation is more nuanced as none of the concepts/dimensions are at maximum over the whole period of time, and developments can differ per scenario, and in the German cases also per aFMM. In Sweden, for example, the naturalness/wilderness dimension increases from minimum to almost maximum in all scenarios, due to the increasing amount of dead wood present over time. In contrast, ephemera reaches a maximum in the EU Bioenergy scenario, but is almost minimised in the Global Bioenergy scenario, due to a reduction of deciduous forests.

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4 Synthesis

Almost trivial to state, the results obtained for the alternative forest management models as presented above reflect the heterogeneity of landscapes, forests, forestry and – even more than D3.2 which was about the current forest management (ALTERFOR WP3 Leaders, 2018c) - the forest management goals across Europe. Probably more interesting, the global frame scenarios with their climate and demand differentiation had in general no pronounced effects; this may be partly due to methodological reasons (as mentioned in some of the ES expert reports), but also to the fact that forests are slow-developing systems whose behavior is dominated by lots of negative feedback loops creating a remarkable degree of inertia and resilience. In addition, the global frame scenarios in ALTERFOR realistically reflect the gradual nature of climate change, keeping most tree species in their climatic 'comfort zone', or at least not too far out of it, for a significant proportion of the covered time span.

A few interesting insights emerge when interpreting the ES provision results in a synoptic way. Sustainable timber supply seems possible on high levels in all three global frame scenarios; this might, however, be not enough to satisfy the timber demand under the Global Bioenergy scenario. It stands to question, if such a lack of increase in timber supply influences the feasibility of this scenario's expected climate change mitigation effect. Many of the ALTERFOR case study areas, however, were selected in order to represent strong conflicts between multiple ESs. This might imply that increasing harvest volumes especially in these regions was more difficult than in each country's overall forest estate, thus exaggerating a possible future timber supply problem.

In any case, what was mentioned above about timber supply and demand, and their relation to climate change mitigation, should be considered in the context of the results obtained for carbon sequestration. Clearly, 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. However, for the considered time span of 100 years the simulations show that overall C sequestration may be maximised if sequestration in the forest is prioritized. 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.

Lower harvest rates as implied by management strategies closer to the second, the low-impact strategy, would consistently increase a forest landscape's recreational value. Throughout all case study areas, (strong) harvesting activities turned out as an important source of (negative) influence to the recreation value. In many cases, lower harvest intensities also coincided with higher biodiversity. This

being said, the link between forest management and biodiversity was not consistent among the case studies. Obviously, initial local conditions, e.g. initial shares of introduced tree species, stand type frequencies, etc., seem to have a considerable impact on how a given forest management model affects biodiversity. The set of forest traits which are key to biodiversity (large trees, deadwood, species composition), however, is largely similar for all case studies, providing opportunities for defining consistent strategies for achieving regional biodiversity goals across large parts of Europe.

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, resulting from low impact management, usually are more risk-prone (especially in terms of windthrow and snow damage) than (thinned) stands with lower densities. In the latter case, the single trees can develop more individual stability in the long run, while in dense stands stability is only maintained as long as the whole collective remains intactDeadwood accumulating due to low impact forestry may also become a risk factor with regard to wildfires. Thus, the degree of desired risk avoidance certainly will be a restriction on low-impact management. A promising general insight from the aFMM results is, however, that the applied aFMMs usually do either decrease or at least not increase the long-term risks.

In some cases, high-intensity forest management conflicted with water-related services by creating unsuitable stand structures and species compositions. Conflicts with water related services, especially erosion protection, were found in situations where fire risk mitigation measures, or the provision of recreation-friendly landscapes, increased the erosion potential. Similar as with biodiversity, local or regional conditions seem to have a strong impact on how forest management influences the provision of water-related ESs.

As a concluding statement, it is worthwhile to repeat and emphasise even more what was stated at the end of D3.2 (ALTERFOR WP3 Leaders, 2018c): The report at hand outlines a state-of-the-art European perspective on forest management and the provision of forest ESs throughout Europe. ALTERFOR will have contributed to advance this state-of-the-art: since the completion of D3.2 considerable effort has been invested in improving the applied DSS models' capabilities to cope with the task of providing ES projections for large forested landscapes while maintaining down-to-stand-level silvicultural diversity. The degree of detail in the silvicultural scenario and associated ES provision modelling, while embedded in large-scale market and climate change scenarios and stakeholder preference research, is, to our knowledge, unprecedented for such a large collection of forest DSS/models and variety of 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). On the one hand, this requires that climate scenarios contain information about the frequency and intensity of such events. On the other hand, this also requires that forest simulation models and DSSs are able to simulate the impact of such stochastic events on stands, stand structures and landscapes at a sufficient level of detail.

While this compilation of results for alternative forest management models clearly indicates the potential to increase the provision of all considered ESs individually, the obtainable synergies and tradeoffs often vary from region to region due to their specific (forest) conditions, history, and social and regulatory requirements. This could be used as an argument against overly uniform EU forest policies. It can also be used as an argument for the crucial role of simulation and optimisation models

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in the exploration of forest dynamics and ES provisioning at the landscape level under complex changing global and local conditions.

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