OptFor-EU

D2.1. Forest Management Practices and their relevance in case study areas

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About OptFor-EU

OptFor-EU wants to co-develop a Decision Support System (DSS) with forest managers and other forest stakeholders, that provides them with suitable climate adaptation and mitigation options for science-based optimising forest ecosystem services (FES) (including decarbonisation) and enhancing forest resilience and its capacities to mitigate climate change across Europe.

The project 'OPTimising FORest management decisions for a low-carbon, climate resilient future in Europe (OptFor-EU)' will build a Decision Support System (DSS) to provide forest managers and other relevant stakeholders with tailored options for optimising decarbonisation and other Forest Ecosystem Services (FES) across Europe.

Based on exploitation of existing data sources, use of novel Essential Forest Mitigation Indicators and relationships between climate drivers, forest responses and ecosystem services, OptFor-EU has five specific objectives:

- Provide an improved characterisation of the Forest-Climate Nexus and FES;
- Utilise end-user focused process modeling;
- Empower forest end-users to make informed decisions to enhance forest resilience and decarbonisation;
- Provide a novel DSS service; and
- Bridging different EU strategic priorities, robust science, and stakeholders in the forest and forest-based sectors.

Based on a supply-demand approach, the methodology combines an iterative process of data consolidation, modeling, and co-development of solutions alongside forest managers and other practice stakeholders in all European Forest Types. The DSS will be designed and tested at 8 case study areas, to provide a ready-to-use service, near to operational (TRL7) at European level, while a user adoption and up-take plan will maximise the societal and business impact.

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EXECUTIVE SUMMARY

The present deliverable reports on forest management practices in the case study areas (CSAs) of OptFor-EU and their relevance in the CSAs.

The first section includes the context of this deliverable.

The second section includes the general modeling framework, a literature review of forest management practices, detailed descriptions of current management in the eight case study areas and the coverage of case study areas with the European Forest Types.

The third section of the deliverable reports the simulation protocol to be used in WP2 (Modeling the F-C Nexus), including the methods used for stand initialization and descriptions for output variables, to be used in the DSS and as input to other models.

The final part is a synthesis and summary of next steps.

1. Context

Modeling can serve as an analytical tool to understand drivers and interactions in ecosystems, help assess potential future scenarios and make informed decisions understanding the current and future implications of the chosen options. The latter is especially important in forest ecosystems, given their slow growth and long-living nature of trees.

WP2 will utilize different model types, including forest models, climate models and vegetation models. Modeling is commonly done for defined forest areas, such as forest stands or spatial pixels of a map.

In the context of the OptFor-EU project and in this deliverable, we define forest management practices (FMP) to be used in forest models. We will use existing FMPs, mainly business as usual (BAU) and no management (NOM). We will build upon outcomes of finished research projects to define these FMPs.

The workflow in Figure 1 shows the main steps to start a simulation, where defining FMPs is an important part, as most of European forests are managed (FOREST EUROPE 2020). Thus any model aiming to deliver accurate unbiased results requires implemented management routines.

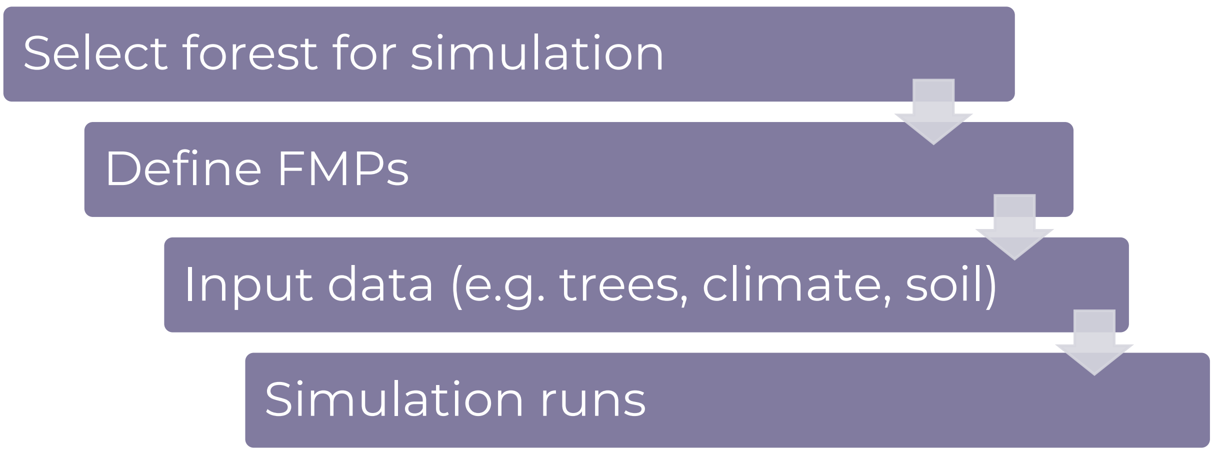

Fig. 1: Workflow of conducting simulation runs with forest models, PICUS and 3D-CMCC-FEM.

2. Forest management practices

2.1. Literature review

We did a review of finished projects that collated information on forest management practices and implemented these into forest modeling frameworks.

FORMIT management strategies (Härkönen et al. 2019):

- short rotation
- coppice
- coppice with standards
- even-aged management with shelterwood
- even-aged management with clearcut
- continuous cover forestry
- no harvest

Härkönen et al. (2019) defined these management strategies for 7 tree species groups (light demanding conifers, shade tolerant conifers, mediterranean conifers, fast growing deciduous, slow growing light demanding deciduous, slow growing shade tolerant deciduous, mediterranean evergreen broadleaves). The authors used FORMIT-M, a newly developed open-access, climate-sensitive forest management simulator. Forest initialization was accomplished using national forest inventory data (Neumann et al. 2016).

FORMASAM management strategies (Reyer et al. 2020):

- Current-Site-Specific (mostly even-aged clearcut), but also shelterwood, target-focussed harvesting diameter-focussed
- Current-Site-Specific (mostly even-aged clearcut), but also shelterwood, target diameter-focussed harvesting
- Bioenergy
- Harvested Wood Products (HWP)
- Multifunctional Adapted.

FORMASAM developed future forest management scenarios with focus on increasing forest resilience and contributions to the bioeconomy. It utilized the PROFOUND database (Reyer et al. 2020) and nine forest sites from Germany, Italy, Finland, France, Czech republic and Denmark for stand initialization.

ISIMIP management strategies (Frieler et al. 2017, https://www.isimip.org/protocol/2b/):

- thinning regime (from above and/or below)
- thinning intensity (from above and/or below)
- harvesting (clear cut) and replanting (by the same species with defined age, stem diameter, tree height, and tree density per hectare)

In OptFor-EU, we propose to use the following forest management practices (FMPs):

- Business as usual (BAU)
- No harvest management (NOM)
- Adaptive forest management (AFM) will be developed in D2.2

BAU is the current typical forest management done in a particular case study area. BAU will depend on site condition, management history, forest ownership etc. These effects will usually vary by country. Thus, BAU will be defined for each case study area separately. There may be several BAU defined for one forest type. BAU implies that human interventions are done, such as removing or planting trees. BAU may only have interventions in selected development stages of a forest, e.g. only early tending or only late thinnings in natural-occurring regeneration. Typical components of BAU are: thinning timing and thinning intensity, selecting desired tree species, rotation age (or target diameter) and process of stand regeneration (artificial, natural).

NOM can have various reasons, including (1) legal restrictions or formal set-aside (e.g. National parks, nature reserves, old-growth forests) and (2) economical reasons or forest owner decisions (e.g. forests that are difficult to access, forests with low quality or no demand for forest products). NOM considered here focuses on the first cluster of reasons for no management. Where possible, we elaborate here the reasons for NOM. In both cases, NOM will likely maximize *in-situ* carbon storage and biodiversity of species that rely on deadwood and closed canopies, such as wood-dwelling insects and/or fungi (e.g. Vitkova et al. 2018, Mayer et al. 2020).

AFM can be modifications of existing management practices, management previously not used in the target region, but used in another region or completely new management practices. Development and implementation of AFM aim to address shortcomings in BAU or NOM and/or anticipate expected adverse consequences due to current management and climate change. Examples are continuous cover management, harvesting only trees exceeding target diameter, introducing novel species or hydrology-oriented silviculture.

2.2. BAU and NOM descriptions

We conducted literature reviews, analysis of geospatial and forest inventory data and informal interviews with forest managers, to collate information on BAU and NOM for the case study area.

2.2.1. Norway (CSA1)

The Norwegian case study consists of the forests of Vestfold and Telemark county. The total area is 1,6 million hectares (16.000 m2), of which 64% (1 million hectares) are forested. Norwegian forest management does not operate with the managed/unmanaged forest distinction. Forest owners and associations instead talk about productive and non-productive forest, where non-productive forest are:

- Protected forests, such as nature preserves, areas rich in biodiversity, of extra importance for wild reindeer, tourism or voluntarily preserved. This makes up 5,8% of the forest in the CSA
- Too far away from forest/logging roads for the forest to be accessible for heavy machinery
- Geologically challenging areas, such as steep hills or other areas where machines cannot access safely - or areas where harvesting would lead to lasting damage to nature, increased risk of flooding or landslides etc. Forest owners are required to register biodiversity as part of the PEFC standard, and forest owners who do not adhere to the standard will not be able to sell any trees. Biodiversity areas are registered and accessible in NIBIO's GIS solution.

In CSA1, 690.000 hectares are considered to be productive forest with in 2021, 1.260.000 m3 wood harvested. 3 million trees were planted across 10.000 hectares (1.4% of forest area with an average planting density of 300 ha-1). Annually, forest owners conduct young growth tending (additional planting, removal of unwanted species or narrow-spaced trees) of 12.500 - 18.000 hectares (1.8-2.6% of forest area). That means approximately 2% of the productive forest is tended each year and 1.4% is subject to tree planting, while 16% of productive forest is estimated to be young and potentially in need of care. This underpins that only a fraction of the forest area is subject to active management.

Forest management is complicated due to ownership and in CSA1, there are more than 10.000 forest owners. On average, 51% of the forest owners report harvesting activities, with the remainder can be considered as not actively harvesting wood.

There are 3 major forest owners in CSA1, Cappelen, Fritzøe and Løvenskiold-Fossum. Together, they own 350.000 hectares of productive forest, about half the total forest area. In addition, there are 19 forest owner associations organized under the AT Forest owners' cooperative. Satellite analysis of the period from 2010-2020 shows that on average, 0,6% of productive forests were harvested each year. With the same level of activity, 47% of the productive forest will be harvested over an 80-year period. The state ombudsman says that it is most likely we will see the same areas harvested again after 80 years and that an increase of harvested area is unlikely. Table 1 shows how the Norwegian forests are categorized with regards to harvest readiness and necessary management.

Table 1: Forest categories in CSA1 (Norway), share and descriptions.

Category	Share at CSA1	Description
HKL1	2%	Recently harvested area, to be planted or regenerated naturally
HKL2	16%	Young forest (sub-categories for adequate/inadequate density). This is the category where most tending occurs.
HKL3	20%	Young production-ready forest. Pre-commercial thinnings can provide some revenue.
HKL4	21%	Older production-ready forest. Almost ready for harvest. Thinning needed, if stands did not already receive tending.
HKL5	41%	Mature forest ready for harvest. Final harvest possible. No considerable volume growth expected.

Main EFTs are EFT1 and EFT2, which are coniferous (800.000 hectares) or broadleaf-coniferous mixed forest (62.000 hectares), dominated by *Picea abies*, *Pinus sylvestris*, *Betula* sp. or other broadleaves. BAU for spruce-dominated forests on productive sites the following interventions are used:

New stand is established with planting or natural regeneration. At 5-15 years non-commercial thinning is done to 1300 trees per hectare. First commercial thinning when dominant height reaches 14 m, down to 800-1000 trees per hectare. Only 10-20% stands are commercially thinned. At a stand age of 30-40 years typical stem density is 1200 trees per hectare (>5 cm DBH) based on spatial datasets. Branch pruning is rarely done, but may improve wood quality considerably. Final harvesting using clear cuts is usually done between 55 and 75 years. Harvesting age is younger in Vestfold and older in Telemark due to differences in climatic conditions.

The national regulations and guidelines for management do not differ greatly between forest types. EFT1 and EFT2 have almost the same guidelines, while broadleaved forests do not have any explicit guidelines for management (in part due to low production and quality. Birch is mainly used for firewood). The main difference is in area coverage. For pine, the target density after thinning is 20-32 m2/ha in the richest soil types at a tree height of 15-20 m, while for spruces the target is 25-30 m2/ha at the same tree height. Table 2 summarizes the general guidelines for management.

Table 2: General management guidelines for EFT1 and EFT2 (partly after data from the [Norwegian forestry extension institute](#))

Stand criteria	Measure
tree height 1-5 meters, or 5 years after planting	"Nursing" stage, where broadleaved trees are removed and distance between trees to target distance of 2,6 m at 150 trees/ha, or 2 m at 250 ha-1 is regulated
tree height 9-13 meters	Pruning and topping might be required, especially if there are still many broadleaf trees
tree height 13-19 meters	Pre-clearing about a year before thinning. Remove trees with diameter smaller than 8 cm at breast height, to ensure easy access for log harvesting machinery. If inadequate nursing: Thinning to the targets mentioned above.
Stand age 55 to 75 years	Final harvesting

Overall, forest management is mainly done for young and newly planted forest, where the purpose is to reach the targeted distance between trees. Other measures (thinning, pruning, etc) are secondary and the guidelines state that nursing during the first 5 to 10 years is by far the most important value-increasing measure.

2.2.2. Lithuania (CSA2)

The Lithuanian case study comprises the protected areas of Čepkeliai State Nature Reserve and Dzūkija National Park. The total area of the case study is approximately 69,675.34 ha, of which 83% (57,870.34 ha) is covered by forests. Forest ownership is quite balanced with state owned forests occupying an area of 26856.31 ha (46.41% of the total forest) and private forest areas occupying 31014.61 ha (53.59% of the total forest).

Forest types in the case study include Hemiboreal and nemoral coniferous and mixed broadleaved-coniferous forest (ETF 2), Mesophytic deciduous forest (ETF 5), Mire and swamp forest (ETF 11), and floodplain forests (ETF 12):

- ETF 2 covers a forest area of 50298.05 ha (87.4%). The most dominant tree species in EFT2 is *Pinus sylvestris* (91.3%).

- EFT 5 covers a forested area of 1528.91 ha (2.7%) and the most dominant tree species are *Alnus glutinosa* (43.1%) and *Betula* sp. (24.6%).
- EFT 11 covers a forested area of 2748.39 (4.8%) and the most dominant tree species is *Pinus sylvestris* (95.8%).
- EFT 12 covers a forested area of 3003.75 ha (5.2%) and the most dominant tree species are *Alnus glutinosa* (38.9%) and *Pinus sylvestris* (24.1%).

In terms of management, according to Lithuanian Forest Law https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.6036/asr forests are divided into 4 groups:

Group I - Forest Reserves (circa 10621.07 ha - 18.51% of the total forest area): state natural reserves, state parks, and natural reserves and reserve districts located in the biosphere monitoring (monitoring) territories. The goal is to create conditions for forests to grow naturally. Forest felling is prohibited, except for the cases provided for in the Law on Protected Areas of the Republic of Lithuania and the regulations of reserves.

Group II - **Special-purpose forests**

- **IIA** (circa 6370.48 ha - 11.10% of the total forest area) - Forests for protection of ecosystems: forests are parts of landscape, telmological, pedological, botanical, zoological, botanical-zoological reserves, anti-erosion forests. The goal is to preserve or restore forest ecosystems or their individual components.
- **IIB** (circa 374.62 ha - 0.65% of the total forest area) **-** Recreational forests: forest parks, urban forests, forests in state park recreational areas, recreational forest plots and other recreational forests. The goal is to form and preserve a recreational forest environment.

Group III - Protective forests (circa 20364.88 ha - 35.49% of the total forest area): These are forests of genetic, geological, geomorphological, hydrographic, cultural reserves or their parts, cultural reserves, regeneration and genetic plots, forest seed stands, field protection, protection zone forests. The goal is to form productive stands capable of protecting the soil, air, water, and human living environment.

Group IV A – Commercial forests of normal felling age (circa 19653.10 ha -34.25% of the total forest area): The purpose is to form productive stands and supply wood continuously in compliance with environmental protection requirements.

BAU – current forest management practices (per forest group):

In general, two different types of management are envisaged in the Forest Law of Lithuania: forest cutting and reforestation.

Source: https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.364764/MhdKMxFykZ

Forest cuttings are divided into 4 types: main cuttings (subdivided into selective, occasional and clear-cuts), silvicultural (educational) cuttings, sanitary cuttings, and special cuttings. Each type of forest cutting follows strict rules for each forest type and tree species, in respect to minimum age of maturity and cutting area (Table 3). The intensity of each forest thinning (young stand formation, thinning, precommercial thinning) varies depending on the forest type (broadleaf and needleleaf), stand (pure or mixed) and tree species. The rules defined in Annex III, IV, V of the legal act "Approval of forest cutting rules" D1-79, state thinning intensity ranging between 20-50% for mixed stands and 10-40% for pure stands. For example, for pure pine forests with average tree height of 5 meters and average diameter 8 cm, the thinning intensity would be 20%. For mixed pine forests and/or hardwoods the thinning intensity is 30%. The thinning intensity will follow as guidelines the minimum number of trees per hectare (for specific soil types) defined in Annex IV of the legal act. For example, for pine forests with average tree height of 6 meters, the minimum number of trees per hectare left after thinning should be at least 3500 trees per hectare. We assume one felling in young stand formation and 2-3 thinnings, depending on felling age.

Table 3: Legal restrictions applied to forest management (example of clearcutting) (adapted from the *National Forestry Accounting Plan by Lithuania* prepared by the Ministry of Environment of Lithuania).

	Minimum age of final fellings			Intermediate fellings (age)			Maximum clearcut area (ha)	
Species	IV *	III *	II **	Young stand formation	Thinning	Precommercial thinning	IV	III
Pinus sylvestris	101	111	170	8-21	21-41	>41	8	5
Picea abies	71	81	120	8-21	21-41	>41	8	5
Betula sp.	61	61	90	8-21	21 - 41	>41	8	5
Populus tremula	41	41	60	8-21	21-31	>31	8	5
Alnus glutinosa	61	61	90	8-21	21-31	>31	8	5
Alnus incana	31	31	50	8-21	21-31	>31	8	5
Quercus robur	121	141	200	8-21	21-41	>41	8	5
Fraxinus excelsior	101	111	170	8-21	21-41	>41	8	5

* clearcut allowed; ** clearcut not allowed

Reforestation rules are defined in the legal act D1-199 "Regarding the approval of forest restoration and planting regulations". Annex III and IV of the legal act defined the composition of species to be planted per each forest type as well as the minimum density of planted trees per hectare. In general, the number ranges from ≥ 1.2 to ≥ 5 thousand units per hectare. For example, in pine forests should be done ensuring a density of ≥ 5000 trees per hectare, for spruce and birch trees a density of ≥ 3000 ha-1.

Group I:

- No management is allowed; natural regeneration is preferred to maintain natural growth. In exceptional cases (provided for in the Law on Protected Areas of the Republic of Lithuania and the regulations of reserves), forest felling can occur.

Group II - Special-purpose forests

IIA:

- clear-cuts and main forest felling is prohibited, and occasional felling is prohibited in stands that have not reached natural maturity. Silviculture cuttings, sanitary cuttings, special purpose cuttings, occur, following the rules established in Table 3.
- Natural and artificial reforestation. Composition of plantations must contain more than 75% of tree species defined in the forest law (very specific tree species composition by forest type).

IIB:

- In the stands of this group of forests, clear-cutting is prohibited, and random main forest cutting is prohibited in stands that have not reached natural maturity. Silviculture cuttings, sanitary cuttings, special purpose cuttings, occur, following the rules established in Table 3. Felling is prohibited during the recreation season (April to September), with the exception of stands damaged by natural or biotic factors.
- Natural and artificial reforestation. Composition of plantations must contain more than 75% of tree species defined in the forest law (very specific tree species composition by forest type).

Group III

- Continuous primary logging is prohibited in national parks, except for swamp and waterlogged vegetation stands. The area of the exchange of continuous main forest cuttings cannot be more than 5 hectares.

- Natural and artificial reforestation. Composition of plantations must contain more than 75% of tree species defined in the forest law (very specific tree species composition by forest type).

Group IV A

- Clear-cutting of the main forest in national parks is prohibited, except for bog and waterlogged vegetation stands. Occasional and selective cuttings, silviculture cuttings, sanitary cuttings, special purpose cuttings, can occur following the rules set in Table 3. The clearing area of clear primary forest cuttings, except clear sanitary forest cuttings, cannot exceed 8 hectares.
- Natural and artificial reforestation. Composition of plantations must contain more than 75% of tree species defined in the forest law (very specific tree species composition by forest type).

2.2.3. United Kingdom (CSA3)

Wytham Woods has management plants for the time period 2021 – 2025 by forest class. These forest classes include (1) minimum intervention woodland, (2) Ancient semi-natural woodland, (3) Recent semi-natural woodland, (4) Twentieth century plantations established on open ground and (5) coppice-managed *Castanea sativa* stands. For consistency with other case study areas we assign these forest classes to the EFT classes. The main EFTs are EFT5 mesophytic deciduous forests and EFT12 floodplain forests. Based on species dominance we assign the forest classes to EFT5.

Management focuses to promote and facilitate natural processes and limit the spread of sudden oak disease, which was detected in oak trees of all ages using aerial infrared photography and tree cores. Reduced vitality may be caused by prolonged spring or summer drought.

EFT5, NOM

This includes “Minimum intervention woodland” and “Ancient semi-natural woodland”, which encompass disturbed ancient woodland, young stands and mainly disturbed ancient woodland, mature stands, ancient woodland which was disturbed by planting in the nineteenth century and 1945-63 period with the results that the stands are now often sycamore-dominated high forest.

Abundant species are *Quercus robur*, *Acer pseudoplatanus* and admixtures are Holly (*Ilex aquifolium*) and European Ash (*Fraxinus excelsior*).

There has been little management within the stands in the last 40 years, apart from a couple of enclosures established in 1992. This woodland has a diverse structure already; is relatively free from non-native/invasive species; and has a relatively high level of mature timber and deadwood. There are currently no plans to use tree planting in this working circle, even if large canopy gaps arise from the loss of ash. The stands are assumed to be unmanaged.

EFT5, BAU

This includes "Recent semi-natural woodland".

Abundant species are *Fraxinus excelsior* and *Fagus sylvatica*, admixed are *Acer pseudoplatanus, Tilia x. europaea* (common lime) and *Castanea sativa* (Sweet chestnut).

Selected old oaks are supported by removing competitors, natural treefall gaps are left for natural regeneration, no deadwood removal, except for small amounts of small diameter material produced during haloing operations

The two following forest types cannot be assigned to the EFT system:

There are small areas with forest plantations established on open ground in the 20th century. Planted species were often conifers, such as *Picea abies, Pinus sylvestris* or *Larix* sp. Now native species often predominate in the stands, either planted or naturally regenerated. Most of the conifers have now been removed or died. Current management aims to develop the stands towards broadleaved high forest. To this end, 60-70% of stems are removed within compartments, leaving all mature broadleaved trees and the conifers *Taxus baccata* and *Pinus sylvestris*.

Small areas of Chestnut Coppice stands exist. The management here continues as clearcuts of up to 1 hectare, as opportunities permit. There are plans to establish a more formal coppice rotation in Bean Wood with about 1 ha cut and regenerated every few years.

2.2.4. Germany (CSA4)

The German CSA is the federal state of Lower Saxony, has a total area of 4,763,500 ha and is forested by around 25% (i.e. 1,204,591 ha). Main forest types are the following: EFT 2 (Hemiboreal and nemoral coniferous and mixed broadleaved-coniferous forest), EFT 5 (mesophytic deciduous broadleaved and coniferous-broadleaved forests), EFT 6 (Beech forest), and EFT 7 (Mountain Beech forest). The proportions of regeneration across Lower Saxony are circa 15% planting and 78% natural regeneration (remaining shares are regeneration from coppice shoots, seeding or unknown).

EFT 2

BAU for conifers (EFT 2): *Picea abies* (Norway spruce)-dominated stands are thinned every 5 years in the first 20 years. Then again at the age of 30 years and subsequently every 20 years. Timber harvest is usually at 80-120 years (or DBH exceeding 45 - 50 cm), just in case of export wood earlier (70-80 years). The number of stems at the beginning of the rotation period is around 2,000 - 2,500 per hectare, but is often initially higher with around 3,000 - 4,000 per hectare. During thinning, 1-2 competitors are removed per target tree (Z-Baum); 60 m3/ha are not exceeded. The number of target trees is 150 – 250 per hectare.

*Pinus sylvestris (*Scots pine) as a light-demanding tree species has the greatest growth in its youth. Accordingly, Scots pine (dominated) stands need a lot of care in the first decades, i.e. a negative selection (Läuterung) at the beginning. The first thinning focuses on promoting target trees. Subsequently, thinning is conducted every 5 or 10 years. From a stand age of 50 years onwards, thinning measures are only carried out every 10 or 15 years. Trees are harvested at the age of 90 to 120 (sometimes 140) years (or DBH exceeding 40 - 55 cm). The stem number at the beginning of the rotation period for pine trees is 2,500-3,200 per hectare. During thinning, up to 3 competitors are removed, and later up to 2 competitors. The number of target trees is up to 250 per hectare.

EFT 5

BAU in Oak (dominated) stands mostly consist of *Quercus petraea* and *Quercus robur*, for which the same management strategies are used. Oak stands are moderately but often treated (and not rare and strong). A two-phase treatment concept applies here. Younger stands (tree height about 15-17 m) are thinned 2 to 3 times per decade. Older stands (with tree height about 25 m) are only thinned once to twice per decade, where one or two competing trees are removed per target tree. Trees are harvested at the age of 200 years or more (or DBH exceeding 60 cm). The number of stems at the beginning of the rotation period is up to 3,000 per hectare. In general, oak is very often planted. During thinning, 1 to 2 competitors per target tree are removed; mixed tree species growing from the shelter into the crown space are always removed. The number of target trees for oak is 120-140 per hectare.

EFT 6 and 7

For BAU in *Fagus sylvatica* (European beech) forest management starts comparably late after 20 to 25 years, where a negative selection is done, removing undesired trees (large crown, poor stem shape) without promoting specific individuals (in German “Läuterung”). Around the age of 40 years first light thinning takes place (removal of 1 to 3 oppressors, later less). Subsequently, thinning is conducted every 10 years if possible. Trees are harvested at the age of 140-160 years (or DBH exceeding 50 cm). The stem number at the beginning of the rotation period for beech is up to 4,000 ha^{-1}. During thinning, 2 – 3 competitors are removed per target tree, but this does not exceed 60 m^3/ha. The number of target trees for beech 100 – 140 per hectare.

NOM: Forest areas without human intervention as a contribution to the National Biodiversity Strategy (NWE10): 33,320 ha (~2.7% of forest area), the remaining forest areas are managed to a greater or lesser extent.

2.2.5. Austria (CSA5)

The Austrian CSA is the Vienna Woods Biosphere Reserve, located south of Vienna. It covers an area of about 1,000 km^2 and about one quarter of the forests are unmanaged. The majority of the forests are managed by the Austrian Federal Forests and the Administration of the City of Vienna.

Main forest types in the Austrian CSA are Beech forests (EFT 6), Mountain beech forest (EFT 7) and Oak-Hornbeam forests (EFT 5). EFT 6 and 7 is dominated by *Fagus sylvatica,* EFT 5 by *Quercus petraea* and *Carpinus betulus*. Admixtures include *Fraxinus excelsior, Acer pseudoplatanus, Ulmus sp., Betula sp., Populus tremula* and other mostly broadleaf species.

BAU includes thinnings by selecting target trees and shelterwood cuts, as stands approach maturity (100-120 years) to initiate natural regeneration, maintaining the target trees (for EFT5 60-100 ha^{-1}). The target diameter at final harvesting is +60 cm diameter at breast height. For EFT 6 and 7 there are 2-3 thinnings, while for EFT 5 five or more thinnings may be needed. 1-3 competitors are removed per target tree. First thinning in EFT 5 is done when tree height reaches 14-16 m. Time between thinnings is 10-15 years for EFT5 and 30-40 years for EFT6 and EFT7. Thinning is done with mechanized harvesters with skid trails 20 m apart (skid trail width about 4 m). *Quercus petraea* is more light-demanding than *Fagus sylvatica*, yet needs gradual increasing of growth space, to avoid frost damage, snow break, development of epicormic shoots and sudden increases in ring width, which would reduce wood quality (Schönauer 2011, Weinfurter 2021, oral communication Reininger 2023). Planned harvesting age is 120-140 years for *Fagus sylvatica* and 160 years for *Quercus petraea* in management plans, but a reduction of the harvesting age is desired to increase output of valuable timber, if site and stand conditions permit.

2.2.6. Romania (CSA6)

The forest area in the CSA consists of 371,056.00 ha according to the EFT map, out of which 280,202.00 ha is included in the forest management plan. The description of forest management was based on literature and on available descriptions of the state-owned forest (approximately 130,000 ha) based on past management practices. The forest types in the Romanian CSA include Alpine coniferous (EFT 3), Mesophytic deciduous (EFT 5), Mountainous beech (EFT 7), and Plantations and self-sown exotics (EFT 14).

Forests in Romania are considered to be managed either by silvicultural management applied to them or by the obligation for wood traceability and/or strict protection, i.e., the no-intervention management type. Forest management in Romania, and also in the area of the case study, can be summarized into six major groups:

FM1. Clear-cuts.

This type of forest management is characterized by removing all the forest vegetation in the parcel (no more than 3 ha) with one cut. This management is done mainly in forests that do not easily regenerate under shelter such as: *Picea abies, Larix decidua, Pinus nigra, Robinia pesudoacacia, Salix, Populus* and other forest stands strongly affected by wind and show. The treatment can be applied to neighboring forest stands for a period of minimum 3 to 7 years. It can be applied on slopes up to 25%, if no major threats to forest degradation, erosion, or landslides can be expected.

The rotation period depends on tree species and productivity of the forest stand; for coniferous is commonly 110 years, and 15-35 years for the above mentioned broadleaf species.

The regeneration is artificial through planting seedlings.

FM2. Coppice.

It applies to forest plantations of *Robinia pesudoacacia, Salix,* and *Populus*.

The rotation period is around 15-35 years.

The regeneration is natural by sprouting and new shoots from roots.

FM3. Shelterwood.

The Shelterwood forest management system involves gradual, group, and repeated cuts, with the primary goal of fostering regeneration under the shelter of existing trees. A key aspect of this approach is the creation of regeneration gaps within the forest stand area. These gaps, which vary in size and number depending on the forest type and the regeneration stage, provide the necessary conditions for new growth. This system is particularly applicable to production forest areas, but it can also be used in certain types of forests with special protection functions, such as in regenerating oak stands (*Quercus*) and managing mixed stands of *Abies alba* and *Fagus sylvatica*, especially in lowland areas.

The regeneration is natural regeneration under the shelter, and it needs planting seedlings, or direct seeding can be applied.

The rotation period depends on tree species and productivity of the forest stand; for *Fagus sylvatica*, it is, on average, 120 years, and for *Quercus*, it is 130 years.

FM4. Continuous cover or conservation cuts.

It implies a system of continuous intervention and a selective cutting of trees with a constant regeneration process, obtaining or maintaining an uneven-aged forest stand. It is recommended on low slopes and in forest stands with trees with shade or partial shade tolerance (*Abies alba* and mixed stands with *Abies alba* and *Fagus sylvatica*), especially in forest areas with protection/conservation aims.

In the same forest management group, the conservation cuts are also included. This is described as a selective or in small groups system cut designed to maintain or help regeneration and sanitary felling for preserving the health of the forest ecosystem. This system is recommended in forest stands with high slopes, protection purposes, or a high degree of being affected by natural disasters (windthrow, snow breaks, or insect attacks).

The rotation period is not defined.

The regeneration is exclusively natural regeneration.

FM5. No intervention (NOM). For 5252 ha in the CSA, no intervention/ no harvest is allowed in the forest areas. These areas include national parks or primary forest stands (old growth).

FM6. No silvicultural management is applied. These are small, under 10 ha private forest stands where no silvicultural management is applied. Nevertheless, a maximum volume of 5 m^3/yr/ha is allowed.

Thinnings are applied to FM1, FM2, and FM3 with different percentages according to the forest stand species composition and production class (Table 4).

Table 4. Minimum recommended thinning intensities for Romanian forest types in percentage (before intervention) of basal area removed (according to silvicultural norms).

Forest type	Age (years)						
	11-20	21-30	31-40	41-50	51-60	61-70	71-80
EFT 3	-	16	12	10	9	8	7
EFT 5	-	15	13	10	9	8	7
EFT 7	-	13	14	13	12	10	9
EFT 14	15-25	-	-	-	-	-	-

EFT 3: Alpine forest types

EFT3 covers approx. 25% of the case study area and consists of mountain *Picea abies* (Norway spruce) forests, either in pure stands or mixed with silver fir. They are even-aged forests, equally distributed between conservation and protection forests (usually on slopes of 25% or higher) and production forests.

BAU (EFT 3):

Protection (FM4, FM5). For forest areas with a conservation/protection role, the only allowed management type is sanitary cuts (up to 5 m^3/ha/year) and salvage logging with artificial regeneration, if needed.

Production (FM1). Forests with production are thinned, between stand age of 25 years (or 12-13 m mean height) and 80 years, with an intensity ranging from 15% to 20% of the basal area (see Table 4). Thinning is done throughout the whole year, as long as access to forest is possible. Intensity intensity increases with age, with the highest intensity after 40-45 years. Thinning cuts every 5-10 years, with 4-6 interventions per stand. The rotation period for final cutting is 110 years, and only sanitary fellings (up to 5 m^3/ha/year) are allowed between thinning and final cut. Final cuts are clear cuts on a maximum area of 3 hectares. In neighbor stands, clear-cuts are permitted only after the canopy has closed (3-7 years).

EFT 5: Mesophytic deciduous forests

EFT 5 covers approx. 25% and are mixed stands of *Quercus cerris* (Turkey oak), *Quercus petraea* (sessile oak), *Quercus robur* (common or pedunculate oak), *Quercus frainetto* (Hungarian oak), *Carpinus betulus* (European hornbeam), *Fraxinus excelsior, Fraxinus ornus*, *Fraxinus angustifolia* and *Fagus sylvatica*. These are mainly even-aged stands, categorized as production-type forests (90%).

BAU (EFT 5):

Protection (FM4, FM5). For forests with a conservation role (e.g., 10% of EFT 5 type), only sanitary cuts (up to 5 m^3/ha/year) and salvage logging with artificial regeneration, if needed, are allowed.

Production (FM3, FM4). For those in the production management type, the thinnings start at 25-30 years, with moderate to strong interventions (limiting the intervention to 75% of crown cover - see Table 4) every 5-10 years until 75-80 years. Cuts target all the vertical structures of the stand. The fellings follow the procedures described earlier for beech forests. The rotation cycle is 110-140 years. However, the number of interventions can vary based on the shade tolerance of the species mix of the stand, with fewer interventions of higher intensity for shade-intolerant species (3 times) and more interventions of lower intensity for shade-tolerant species (5 times). Natural regeneration is preferred in all cases, and if a closed canopy is not achieved within 3 years, only then artificial regeneration becomes necessary.

EFT 7: Mountain beech forests

EFT 7 is dominated by *Fagus sylvatica* (approx. 50%). They consist of pure stands (1/3 the forest type area) or mixed with *Picea abies* and other broadleaved species. They are evenly distributed between even-aged and uneven-aged stands, primarily as production forests (2/3 of the covered area) rather than for protection or conservation.

BAU (EFT 7):

Protection (FM4, FM5). Forest stands with protection or conservation roles allow only sanitary fellings and salvage logging (if necessary).

Production (FM3). For production-type forests, thinning starts at 20-25 yr, using an up-and-down positive selection strategy to diversify the vertical structure toward a future uneven-aged stand. Thinning frequency is 8-10 years, with an intensity that can reduce crown cover to 75%-80% till 80 years. Between 80-110 yr, only sanitary fellings are permitted. Final cuts are shelterwood cuts, implemented in three stages between 110 and 140 years, creating circular open areas with diameters equal to 1-2 mean heights of the forest stand (around 30% of standing wood). In the next stage, increase opened areas concentrically and in bands (30%), and in the final stage, cuts are made to extract the remaining growing stock (30%).

EFT 14: Plantations and self-sown exotic forests

EFT 14 covers only 1% of the area, consisting of forest stands of *Robinia pseudoacacia* and *Populus* sp. plantations.

BAU (EFT 14): The management approach is coppice with a rotation period of 25-30 years (FM2).

2.2.7. Spain (CSA7)

There are three major plant groups in the Iberian Peninsula. The Atlantic area in the west, where there's little summer water scarcity. The Mediterranean dominates 80% of the Peninsula and the Balearic Islands characterized by hot and dry summers. Species in this group are the richest and most complex due to the adaptation of variants to continentality, subtropical or high aridity that modulate Mediterranean climates. Macaronesia dominates the Canary Islands with Mediterranean-subtropical climate, and contrastive variants from the semidesert coastline to the arid high mountains.

The case study area in Spain is located in the forests of Sierra de Gata and Las Hurdes, two regions in the North of Extremadura (West of Spain). The forest systems of these regions are characterized by:

- Large extensions of *Pinus pinaster* pine forests (EFT 10), some autochthonous areas and large areas from reforestation, from which timber and resin exploitation is obtained.
- Climatic Mediterranean forests, providing many ecosystem services, including high levels of biodiversity are dominated by *Quercus ilex, Quercus pyrenaica* and some *Quercus suber* (EFT 9) and are only managed extensively.
- Dehesas (EFT 9) are *Quercus dominated* forests, that due to centuries of human management have been transformed into the traditional agro-ecosystems of the West of the Iberian Peninsula and are now used for extensive grazing, firewood and cork production.
- Other types of forests: riverside forests play also an important role in these districts, supporting activities such as fishing, erosion protection or rural tourism. Scrublands are also common in this region and their main use is soil protection, hunting, and honey production.

The main distinction in the management of these forests can be established in the ownership regime:

- There are several publicly owned farms, which have an organized and formal forest management, although not entirely efficient, as the lack of economic resources for forest planning and management is noticeable. This is detrimental to the sustainability of these forest systems over time and exposes them to the threats of fire, pests and diseases, drought and erosion.

- On the other hand, private forest ownership faces serious challenges. Except for private forest lands with profitable economic uses mainly for timber or hunting, the high rate of fragmentation of ownership makes forest management difficult, as it makes it economically not feasible. In addition, there is a high number of abandoned forest areas, who are often not even aware of their land, which increases the main risk to the area's forests, namely large forest fires.
- The main functions of these forests are soil protection and forest hydrological regulation, as well as shelter for fauna, hunting and fishing. These forests mainly result from massive reforestation processes undertaken in the 60s and 70s in Spain. Forest exploitation, such as timber production, or resin production are not outstanding, due to the lack of nearby processing industry that would be needed to process and transform forest products at reasonable costs.

BAU for *Pinus pinaster*: Pinus pinaster is already too well established in the area. The natural regeneration of Pinus pinaster is so strong that it is hard to replant with other more ecologically interesting climax species, such as Quercus pyrenaica, Quercus ilex or Quercus suber. Different management practices are defined according to the forest exploitation objective (timber or resin forests).

<u>Timber forests</u>: clear cut at age of 60 years. Initial number of trees is between 1,200-1,500 trees per ha. The final stem number is expected to be 300-350 trees. Thinnings are conducted every 20 years, removing about 30% of stem number. First thinning: removing 500 trees per ha with maximum stands, mean tree height at this stage is about 2-2.5 meters. Second thinning: removing 400 trees per ha and mean tree height is about 4-5 meters. Third thinning: removing 250 trees per ha.

<u>Resin forests</u>: clear cut at age of 60 years. Initial number of trees is between 1,200-1,500 trees per ha. The final stem number is between 200-250 trees. Thinnings are done every 20 years in four stages. First thinning: removing about 600 trees per ha, trees height is about 2-2.5 meters. Second thinning: removing 400 trees per ha and mean tree height is about 4-5 meters. Third thinning: removing 300 trees per ha. The final clearing yields 5% of the initial stands. Resin is extracted after the third thinning, after 40-60 years, with five undercuts per tree. Each undercut produces approximately 2,5 kg per tree per year and a total production of 10,000 kg/ha for 200 trees per hectare, after 20-year resin production period.

BAU for *Quercus ilex* and *Quercus suber*: clear cut at age 150 years. Initial number of trees between 200-625 trees per ha. Thinning every 40 years with an expected cleaning of 20% of the area. Target diameter, before the first intervention is started, is about 15 cm. These stands can be regenerated either natural or artificially. For natural regeneration, the area is closed to grazing for at least 20 years, to ensure sufficient tree density. In case of artificial regeneration, tree plantation density is commonly about 400 trees/ha. Other *Quercus* sp. are managed similarly.

The NOM forests in the case study area have no economic exploitation and no interventions such as thinnings. The main function of these forests is land cover protection, biodiversity maintenance and the hydrological and forest regulation of the basin. Private ownership dominates these forests. According to the forest type, NOM forests are characterized as follows:

The unmanaged Mediterranean *Pinus pinaster* forests generally present major problems of excessive forest density, which makes them forest stands with a high fuel load and a high risk of forest fires. The main reason for non management is related to the abandonment of rural areas, and the lack of technical skills and financial resources of private owners to manage them.

In the case of unmanaged *Quercus pyrenaica* forests, reasons for non management are similar to *Pinus pinaster*. Their ecological quality, though, is higher, as they are closer to the ecological optimum. However, these forest stands in the north of Extremadura are threatened by more severe summer droughts and desertification. Holm oak (*Quercus ilex*) and cork oak (*Quercus suber*) could be natural substitute species in climate change scenarios with higher temperatures and lower precipitation.

2.2.8. Italy (CSA8)

The Italian CSA is the Model Forest of Florentine Mountains (Foresta Modello Montagna Fiorentina - FMMF) in Tuscany, province of Florence. The territory of the FMMF is around 554.800 ha, ranging from 100 to 1600 m a.s.l., with 70% of forest cover. 24% of the forests are unmanaged, 1% are old growth forests and the remaining 75% can be classified as managed. Main forest types are Beech forest and Mountain beech forest (EFTs 6, 7, both dominated by *Fagus sylvatica* and *Abies alba)*, exotic plantations, mainly composed of *Pseudotsuga menziesii* (EFT 14), Mediterranean coniferous forests, dominated by *Pinus* sp. (EFT 10) and mesophytic and thermophilous deciduous forests, dominated by *Quercus, Ostrya, Fraxinus* or *Castanea* (EFTs 5, 8).

BAU for *Abies alba, Pinus* sp., *Pseudotsuga menziesii* and other conifers: clear cut at age 80 years at maximum area of 0.25 hectare, thinnings every 20 years removing max. 10% of canopy cover.

BAU for *Fagus sylvatica* - coppice: cut every 35-40 years, maximum area allowed 10 ha, leaving residual trees at 60 trees/ha 50% of the age of two rotation period, 50% of one rotation period.

BAU for *Fagus sylvatica* - converting coppice to high-forest (from short to long rotation): final cut every 80-100 years, thinnings every 20 years, promoting shade-tolerant species like *Abies alba*, removing max. 10% of canopy cover.

BAU Mesophytic deciduous forest - coppice: cut every 35-40 years, maximum area allowed 20 hectare, leaving residual trees at 60 trees/ha 50% of the age of two rotation period, 50% of one rotation period

BAU Thermophilous deciduous forest - coppice: cut every 35-40 years, Clear cut maximum 20 ha with standards (30 plant/ha 50% of the age of two rotation period, 50% of one rotation period).

The NOM forests in the area can be divided in three categories:

- abandoned forest for which BAU forest management practices are not convenient due to the high cost of forest harvesting (e.g. small forest properties, absence of forest roads) that represents 24% of the total forest area. These areas include Mountain beech forest (EFT 7), Mediterranean *Pinus* sp. (EFT 10), forests dominated by *Quercus, Ostrya, Fraxinus* or *Castanea* (EFTs 5, 7, 8)
- forest left to natural evolution where management plans only involve monitoring the forest's development and can be permitted small silvicultural interventions that are planned to guide the stands towards more complex systems, also increasing the amount of deadwood on the ground. These types of forests are located in National and regional reserves (Vallombrosa Biogenetic Reserve 1000 ha and Sant'Antonio Regional Forest 900 ha). These forests include Beech forest (EFT 7), Mountain beech forest (EFT 7), *Abies alba* (EFT 7), Mediterranean *Pinus* sp. (EFT 10), forests dominated by *Quercus, Ostrya, Fraxinus* or *Castanea* (EFTs 5, 7, 8).
- Old growth forest

2.3. Case study coverage with BAU description and relevance of NOM

We describe here the coverage of the CSAs with available FMP (previous sections) and by quantifying their spatial contribution. Table 5 shows the tabulated share of the 14 European forest types in the eight CSAs using the EFT map from D1.1 (Giannetti and Zorzi 2023). The most frequent EFT across the CSAs is EFT 2 and 5. EFT 1, 3, 6, 7, 8, 11 and 12 are locally important.

Table 5: Tabulated data on cover in percent of EFT in OptFor-EU case study areas.

EFT	Name	NORWAY (CSA1)	LITHUANIA (CSA2)	UK (CSA3)	GERMANY (CSA4)	AUSTRIA (CSA5)	ROMANIA (CSA6)	SPAIN (CSA7)	ITALY (CSA8)
1	Boreal Forest	19.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Hemiboreal and nemoral coniferous and mixed broadleaved-coniferous forest	49.16	87.33	0.00	50.87	0.00	0.00	0.00	0.00
3	Alpine forest	13.44	0.00	0.00	0.00	3.49	16.51	0.00	0.00
4	Acidophilus oak and oak-birch forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Mesophytic deciduous forest	0.45	2.69	61.27	19.08	54.85	40.45	0.00	63.04
6	Beech forest	0.00	0.00	0.00	10.18	25.15	0.00	0.00	0.00
7	Mountainous beech forest	3.67	0.00	0.00	12.65	14.12	41.75	0.00	3.84
8	Thermophilous deciduous forest	0.00	0.00	0.00	0.00	0.01	0.00	14.40	31.87
9	Broadleaved evergreen forest	0.00	0.00	0.00	0.00	0.00	0.00	18.47	0.00
10	Coniferous forest of the Mediterranean, Anatolian and Macaronesian regions	0.00	0.00	0.00	0.00	0.00	0.00	67.09	0.81
11	Mirne and swamp forest	0.91	4.78	0.00	0.21	0.00	0.00	0.00	0.00
12	Floodplain forest	12.47	5.20	38.73	4.95	2.38	0.56	0.00	0.00

13	Non-riverine alder, birch or aspen forest	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Introduced tree species forest	0.00	0.00	0.00	2.06	0.00	0.73	0.04	0.44

Table 6 summarizes the FMPs defined in this document and the extent that these FMPs cover the respective CSA in terms of forest area. We reach coverage greater than 90% in most CSAs.

We also collated information from key stakeholders in the CSAs on the share of NOM in their CSA. The results vary from ~3% to ~100%, as some CSAs are mostly productive and accessible forests with only small protected areas and other CSAs are to a large extent under protection. Many CSAs had shares of NOM between 10 and 30%.

Table 6: Area of case study areas, forest types present in case study area (based on T1.4. map) and forest types covered with FMP description

Country	Area of CSA (approx)	EFT with FMP described in this report	Share of described EFTs at CSA area	Share of unmanaged forests in CSA
Austria	~1000 km2	5, 6, 7	94%	~24%
Germany	~48000 km2	2, 5, 6, 7	93%	~3%
Lithuania	~1000 km2	2, 5, 11, 12	100%	~18% (group 1 forest)
Italy	~800 km2	5, 6, 7, 8, 10, 14	100%	~25% (~1% old growth)
Romania	~18000 km2	3, 5, 7, 14	100%	~25% (~1% old growth)
Norway	~16000 km2	1, 2	87%	~30% (unproductive forests)
United Kingdom	~4 km2	5	100%	100%, management depends on stand structure
Spain	690 km2	9, 10	100% (EFT8 assigned to EFT9)	~12%

3. Simulation protocol

A transparent simulation protocol is needed for efficient, coordinated model applications and utilizing model interfaces and synergies. We collate a database of forest stand information, that serve as stand initialization data for forest models and evaluation/validation data also for other models.

Forest models operate for stands, composed of a finite number of trees, commonly covering an area of about 1 hectare (100 x 100 m). Forest types in a region usually cover a much larger area, which can exceed several km^2 (>100 ha). For efficiency only selected stands are simulated. While PICUS simulates every single tree (hundreds or thousands per stand) and at a monthly temporal scale, 3D-CMCC-FEM simulates the entire stand through a representative-tree approach (the "average tree") but a daily temporal scale.

Determining the size target stand, to be initialized, is a tradeoff between homogeneity, a sufficient number of trees in it and variation of forest structure and size of forest stands in reality (commonly ranging between 0.1 to several hectares). To this end, the represented area should not be below 1000 m^2. Smaller areas may have different variations (larger or smaller) compared to larger forest stands. For example, using a forest area of 10 x 10 m for model initialization, may result in no or only one mature tree within an area 100 m^2 (assuming crown diameter of 10 m).

3.1 Stand initialization

The information for initializing forest stands are tree dimensions (stem diameter at breast height, tree height, crown dimensions), tree properties (tree species, status live-dead, …) and their positions in space (for models considering tree positions). For efficiency, commonly only larger trees are explicitly considered in forest models, e.g. by using diameter and/or height thresholds. Forest measurement systems such as monitoring plots or inventory systems, often apply different measurement procedures for different tree sizes, commonly determined based on diameter. This has to be considered for stand initialization with data not covering the entire size range of trees.

Fig. 2 outlines the stand initialization for PICUS, which is a key part of model application (Fig. 1).

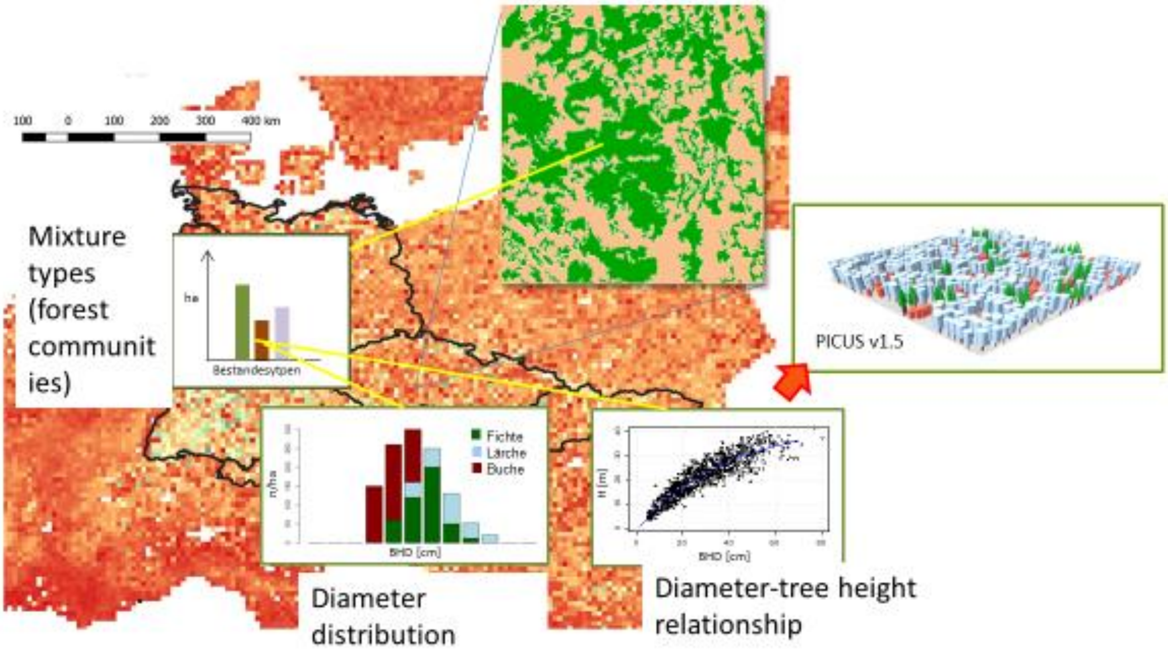

Figure 2: Concept for stand initialization in model PICUS

Stands will be initialized based on observations of sample plots, inventory systems or field surveys. From the actual observed composition of a forest, the forest can be reconstructed for simulation runs. This approach is a simplified version of the "Forest matrix" approach (Dalmonech et al. 2022). The time steps will be in 20-year time steps: e.g. 0, 20, 40, 60, 80, 100 years or equivalent stand development phases, if no stand age information is available.

Forests are commonly a mosaic of different age classes and there are some age classes that are more frequent, e.g. forests originating from an active afforestation period, a large fire event, change in forest management or some forests left unmanaged due to protection areas or economic reasons. The actual frequency of age classes in a forest can be used for upscaling simulation results of single stands to case study level, for instance for estimating total carbon storage.

Fig. 3 outlines the sequence of development stages from young to old trees, including a final natural forest. Not all development stages may be presented in a particular area or in a particular forest type.

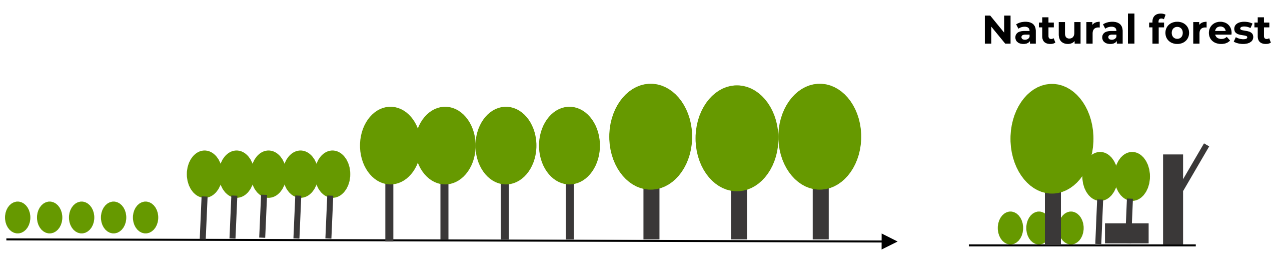

Figure 3: Stand development phases from young to old stand age and a hypothetical natural unmanaged forest

3.1.1. Information sources

Diverse data sources are used to initialize the stands, as data access varies across the countries.

For Romania, inventory data covering the entire case study area will be utilized (~1100 plots, measured in 2012 and 2017). For trees > 5.6 cm DBH (measured within 500 m² plots) we have information on species, diameter, tree height and other parameters. For trees < 5.6 cm DBH we have counts by species and their mean diameter. For these plots we also have information on soil, litter and deadwood carbon stocks.

For Austria, chronosequence data is available for Beech (n = 13) and Oak forest stands (n = 9). For each stand, including deadwood, about 1,000 m² were measured using a combination of angle count sampling, line transects and fixed area plots. For these plots in 2023 detailed measurements of all trees > 0 cm DBH were made, as well as for regeneration, smaller 1.3 m height in three classes. Soil, litter and ground vegetation were measured in terms of mass and carbon content. In addition, we have information from forest management plans, such as forest area and volume.

For Italy, 300 growth plots maintained by Francesca Giannetti (Blue Biloba) and colleagues can be utilized. The sampling system is consistent with the Italian national forest inventory, using a 530 m² sample plot for trees larger 9.5 cm DBH (and 13 and 50 m² subplots for smaller trees).

For Spain, national forest inventory data for about 300 sample plots measured between 2008 and 2018 can be accessed. Trees measured with >7.5 cm DBH. Data is freely available.

For Germany, national forest inventory data measured in 2012 can be accessed. Trees with > 7 cm DBH are measured. About 3700 inventory plots are in the case study area. Data is freely available.

For Norway, gridded forest structure information (spatial resolution 16 x 16 m, about 250 m^2) can be accessed. Data covers trees with stem diameter larger 5 cm at 1.3 m above ground. Data is available for 2012-2020.

For Lithuania, national forest inventory data has been requested to be used within this project.

For the UK, forest inventory data of Wytham Woods is available. Data has been used in scientific publications (Kirby et al. 2014, 2022). Basal area, stem density and species composition is available for 164 plots (10x10 m square plots with 100 m^2) and was measured in 2018. In addition, the basal areas of the surrounding forests around 10x10 m plots were measured using angle count samples. Diameter-height relations and diameter-age relations are available for a sub-sample of trees. Soil organic matter is available. Dead trees were not measured.

3.2 Description of datasets

Transparent and harmonized documentation and formatting of datasets used as model input as well as datasets generated by models are needed. The generated datasets will be stored in the OptFor-EU database (Task 1.3). The main uptake for modelling output will be the DSS Tool (WP4).

3.2.1 Input datasets

For stands selected for simulation, we need for each stand the following variables. We focus on trees that are part of the overstory, by excluding trees smaller 5 cm (in some countries 5.6, 7 or 7.5 cm) for stand initialization.

- Location (WGS84 latitude and longitude)
- Assigned EFT
- Stand age/mean tree age
- Species composition (% of species at total basal area of stand)
- Mean quadratic tree diameter (cm)
- Mean tree height (m)
- Stem density (ha-1)
- Basal area (m^2/ha)
- Volume live trees (m^3/ha)
- Carbon live trees above ground (tC/ha)

3.2.2 Output variables

There are two groups of model output variables: (1) shared variables (used for model cross-comparison) and (2) single-model variables (to be used for follow-up analysis or interpretations). Variables are available for annual time steps, e.g. from year of initialization to 2100.

Shared variables are:

- (variables of input dataset)
- Harvested tree volume in this year (m^3/ha), including saw logs and pulpwood

Single-model variables are, in addition to shared variables listed above:

- Carbon fluxes, like autotrophic respiration, and stocks like harvest woody products (3D-CMCC-FEM) such as in Collalti et al. (2018), Dalmonech et al. (2022) and Testolin et al. (2023)
- Water flux-related parameters, like transpiration or stomatal conductance (3D-CMCC-FEM) to check CO2 fertilization effects
- Interception area of forests for water, snow or air pollutants (through post-processing of model outputs), for instance using leaf and branch functions, such as Hietz et al. (2010), Neumann and Ledermann (2023).
- Soil carbon (PICUS)
- Deadwood carbon (PICUS)
- Bark beetle mortality (PICUS)

4. Conclusions and next steps

All CSAs have descriptions of BAU and the relevance in relation to NOM within the CSA. The management descriptions vary in detail, in parts due to differences in legal regulations and available and documented information. All CSAs have a forest management plan, but the extent of formalization, coverage of forest types and availability varies. We also have a gradient in management intensity, with the CSA3 in the United Kingdom being the least managed CSA. The majority of CSAs feature unmanaged forests (NOM) covering 12 to 25% of forest area, which is considerably larger than the unmanaged share of forests reported in national reports (FOREST EUROPE 2020). The reasons for NOM involved owner decisions, legal restrictions, old-growth conditions, limited accessibility and/or low forest value.

The EFT map allowed a comprehensive and systematic assessment of forest types. Most EFT occur in several CSAs, allowing comparisons and cross-regional analysis. The most widespread forest type is EFT5 Mesophytic deciduous forest, present in all CSAs, apart from Spain. In six CSAs we have a BAU description of EFT5. Beech-dominated forests (EFT6 and 7) occur in six CSAs and have BAU descriptions in four CSAs. Hemiboreal and nemoral forests (EFT2) occur in three CSAs and have BAU descriptions in three CSAs. There are two EFTs that occur only in one CSA (EFT1 boreal forests in Norway, EFT9 Broadleaf evergreen forest in Spain). Some EFT in some CSAs have several BAU descriptions, such as in Romania (CSA6) and Italy (CSA8). BAU often varies by tree species for one forest type (e.g. in Germany separate rules for *Pinus sylvestris* and *Picea abies*). The BAU and NOM descriptions can be now implemented in model routines to simulate the effects of management on forest growth.

The CSAs are up to 48,000 km^2 in size, with all but one greater than 700 km^2. Assuming that forest stands have an average size of 2 hectares, there would be at least 35,000 stands. For efficient simulations of such a large number of stands, we developed a simulation protocol, using (1) region (differences in BAU and NOM description), EFT for describing forest type and age class as proxy for stand development. We collected ground observations from available data sources, to initialized the forest stands for forest simulations.

Modifying current management practices can be tailored as adaptation measures to reach user-defined targets, e.g. ensure extracting fuel wood at defined rate, maintain cooling through transpiration or reach certain habitat targets or carbon storage *in-situ*. This report includes a large variety of FMPs across wide environmental (e.g. climate, soil, local tree species and their gene pool) and social gradients (e.g. ownership structure, markets for forest products, legal constraints). For instance, a management currently used in Germany may become a promising management for Norway in 2100, as climate warming proceeds. Modifying current NOM without wood harvesting by removing or ring-barking selected trees or tree species and increasing deadwood pools (standing or lying) may have positive outcomes for selected biodiversity and habitat indicators.

Next steps include simulating BAU and NOM using the initialization data after assigning CSAs to PICUS and 3D-CMCC-FEM, establishing a link to WP4 (DSS) and WP1 (indicators) and developing new FMP (D2.2) in cooperation with WP3 and WP5.

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