Knowledge and Technologies for Effective Wood Procurement

Deliverable 2.1

Identifying and extending key silvicultural systems

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1 Publishable summary

WP2 is focuses on the optimization of the access to wood resources. This goal involves two main aspects:

1. The application of appropriate harvesting techniques - aiming at the promotion of mechanized systems wherever possible, and
2. The evaluation of appropriate silvicultural operations.

Appropriate silvicultural measures are principally intended to increase wood production, maintain the biodiversity and resilience but also to enable and facilitate the use of efficient silvicultural and harvesting operations. The development of methods for increasing the wood production and optimizing the interface between harvesting technology and silvicultural procedures is the research emphasis of this work package.

Task 1 is charged with the evaluation of the current situation that means the currently practiced main silvicultural systems in the participating countries ("Where are we?"). On that basis the potential to increase wood production is identified. Task 2, as a consequence, aims at formulating research questions ("Where do we want to go?"), and at generating case studies and establishing case study areas, in order to clarify how the identified development potential can be materialized and defined research questions can be achieved ("How do we get there?"). This means that optimal combinations of silvicultural work steps such as choice of species and species mixtures, planting patterns, early operations, thinning regimes and definition of rotation length will be developed and assessed against their feasibility. Task 3 deals with the modelling of identified best practices, in order to make visible the consequences of the suggested improvements and to ensure their long term effect. Task 4 concentrates on the improvement of the sequence of business processes within supply chains of forest based products and services.

2 Introduction

To obtain information about the current situation and to identify key silvicultural systems, the questionnaire for all partners involved in Work Package 2 was prepared. Information collected in the questionnaire was then made available to all project partners. Completion of the questionnaire was based on the use of already available data and expert knowledge. The applied solution allows for compiling the knowledge on specific conditions in different European countries. The results can be used by the project partners for country-wise publications describing key silvicultural systems.

All partners who have filled out the questionnaire also described possible promising options to enhance productivity of silvicultural operations in their local conditions. This knowledge allows for describing trends and offers possibilities to improve the existing key silvicultural systems, in order to achieve this goal on the local and regional scale, as well as to prepare similar ideas for implementation in a European scale.

3 Identified key silvicultural systems

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3.1 Description of the questionnaire as a data source

The questionnaire was provided as an MS Excel spreadsheet with examples to illustrate expected results and guide the people responsible for providing information. The spreadsheet contained 6 parts (sheets):

1. Contact - data of person responsible for filling-in the questionnaire in each country.
2. Silvicultural systems - the aim of this part was to cover the majority of managed forests in the respective country by describing key silvicultural systems. If available, potential options to enhance the productivity of particular silvicultural systems should be highlighted, expressed as forest increment (m^3/ha/year) or as machine productivity (m^3/hour).
3. The number of silvicultural systems for each partner was not fixed. As a guideline, at least 80% of the managed forest area in the country/region should be represented by the described systems.
4. Case studies – provision of meta-information on case study areas. Already existing study regions could be chosen and used as case studies. If certain information was missing, project partners should collect additional data to fill the gaps.
5. Forest management, including early operations – the intention of this part was to describe the forest management systems/options and to cover the whole life time of a tree, from germination/planting to cutting. This part of the questionnaire tried to collect the most important systems across Europe. Involved partners were authorized to include individual systems, if needed to cover the specific features of their country.
6. Harvesting systems – the aim of this part was to capture the most important wood harvesting systems across Europe. Gathered data allowed the comparison of systems used for thinning and final harvesting. Systems - to be comparable - were defined by the same final product (e.g. logs stacked on forest road).
7. Sources - list of literature used to derive information for questionnaire.

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3.2 Results of questionnaire - assessment of the current situation

3.2.1 Description of key silvicultural systems, key management options, main tree species and employed harvesting systems

Data collected by questionnaire are available for nine European countries, which are delineated in Figure 1.

Figure 1 Countries with available data for questionnaire

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In order to use consistent terminology, the key silvicultural systems described by the partners have been condensed in 6 categories, which are listed and described in Table 1. Please note that "Age class forest" is not necessarily connected with clear cut, since it can also be established by a sequence of small-scale-area removals (group cut, gap cut, opening up) in order to harvest mature trees as well as to promote regeneration and control the species mixture of regeneration. That means, "Age class forest" is used as generic category, and "Age class forest / clear cut" is a special characteristic.

Table 1 Definition of key silvicultural systems

Silvicultural system	Description
Age class forest	Even aged high forest. One final cut (clear cut) or various final cuts (group cut, gap cut, opening up). With subsequent artificial or natural regeneration.
Continuous cover forest	Uneven aged high forest with final harvest of single trees ("Plenterwald" / target diameter system). With mostly natural regeneration.
Shelterwood	Even aged high forest. Sequence of final cuts for harvesting mature trees and establishing natural regeneration.
Coppice with standard	Middle forest with two layers: overstory (production of sawn logs) and understory (production of fuel wood, pulpwood).
Coppice	Low forest, vegetative regeneration.
Tree farms	Exclusive or prevalent production function.

The detailed results on key silvicultural systems by country are shown in Table 2.

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Table 2 Questionnaire - Key silvicultural systems by country

Finland					
Key Silvicultural system	**Management system/options**	**Main tree species**	**Early operations**	**Employed harvesting systems**	**Covered forest area**
Age class forest/clear cut	First thinning Intermediate thinning Clear cut	Scots pine	Soil preparation/stand establishment, natural regeneration	Harvester and forwarder	6% (first thinning) 10% (intermediate thinning) 28% (final cutting)
Age class forest/clear cut	First thinning Intermediate thinning Clear cut	Norway spruce	Soil preparation/stand establishment, artificial planting	Harvester and forwarder	2% (first thinning) 6% (intermediate thinning) 33% (final cutting)
Age class forest/clear cut	First thinning Intermediate thinning Clear cut	Silver birch	Soil preparation/stand establishment, artificial planting	Harvester and forwarder	2% (first thinning) 4% (intermediate thinning) 9% (final cutting)
Sources: Finnish Statistical yearbook of Forestry , Metsätilastollinen vuosikirja 2014, Metla					
Norway					
Key Silvicultural system	**Management system/options**	**Main tree species**	**Early operations**	**Employed harvesting systems**	**Covered forest area**
Age class forest/clear cut	First thinning Intermediate thinning Clear cut	Norway Spruce	Artificial regeneration , weeding + precommercial thinning, 2 thinnings, clear - felling (medium to high site classes)	Harvester and forwarder	20%
Age class forest/clear cut	First thinning Intermediate thinning Clear - cut	Scots pine	Seed tree regeneration, tending, thinnings, clear-fellings	Harvester and forwarder	24%
Age class forest/clear	First thinning	Silver birch	Natural regeneration , 1	Harvester and forwarder	31%

cut	Intermediate thinning Clear - cut		thinning, clear-felling		
Age class forest/clear cut	First thinning Intermediate thinning Clear - cut	Mixed Norway spruce + Scots Pine	Weeding, 1(max 2) thinning, clear-felling, planting spruce	Harvester and forwarder	4%
Age class forest/clear cut	First thinning Intermediate thinning Clear - cut	Mixed Norway spruce + Silver birch	Weeding, 1(max 2) thinning, clear-felling, planting spruce	Harvester and forwarder	6%
Source: Norwegian National Forest Inventory (NNFI) 2014					

Denmark

Key Silvicultural system	Management system/options	Main tree species	Early operations	Employed harvesting systems	Covered forest area
Age class forest/clear cut monocultures/mixed stands	Clear cut stand wise or clear cut in strip or wedge patterns. Normally followed by planting in fewer cases sowing either artificial or natural from a few left over neighboring trees Rotation age 40 - 150 years	Spruce – fir – pine –larch – Douglas fir – beech – oak – ash – maple – cherry -others		Early thinnings: chainsaw or fellerbuncher - eventually forwarder - and chipper. Later thinnings: Harvester - forwarder and chipper. Final harvest conifers: harvester - forwarder or skidder (eventually winch supported) and chipper. Final harvest broadleaves: Chainsaw - skidder (eventually winch supported) / forwarder and chipper	66%
Shelter wood.	Regeneration time up to 20 years Regeneration by seeds often combined with supplementary planting of other species	Beech (supplementary species e.g. Larch, Douglas fir, Sitka and Norway spruce)		Early thinnings: chainsaw or fellerbuncher - eventually forwarder - and chipper. Later thinnings: harvester - forwarder and chipper. Final harvest: chainsaw - skidder (eventually winch supported) / forwarder and chipper	9%
Continuous cover forest, "Plenterwald", typically mixed	Reduced impact logging or group wise regeneration.	Beech-Oak-others		Chainsaw - skidder (eventually winch supported) / forwarder and chipper	8% (Becoming more common)

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stands					
Coppice - mixed hardwood	Rotation age 40-50 years	Oak-Alder-Maple-Beech-Hornbeam-others		Chainsaw or harvester - forwarder - chipper	1% (Occasionally)
Coppice	Short rotation 10-20 years	Popular		Chainsaw, harvester or feller buncher - chipper or forwarder-chipper	Becoming more common
Coppice with standard	Rotation age under story e.g. 20 years. Standards e.g. 100 years. Additional standards are selected after each coppice operation.	Oak-Beech-Hornbeam-others		Chainsaw or harvester - forwarder / skidder - chipper	Very Rare

Sources: C. M. Møller. Vore skovtræarter og deres dyrkning, 1965
H.A. Henriksen, Skoven og dens dyrkning, 1988
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R. K. Nygaard. Kvalitetssikring i unge løvtræbevoksninger, bachelor thesis, 2016
A. Bergstedt. Skovdyrkning i praksis, 2017

Poland

Key Silvicultural system	Management system/options	Main tree species	Early operations	Employed harvesting systems	Covered forest area
Age class forest/clear cut	Clear cut, wide strip 60 - 80 m, strip 40-60 m	Scots pine	Soil preparation natural regeneration + artificial from plantation, type of seedling: bare-rooted plant	Chainsaw-tractor, chainsaw-skidder, harvester-forwarder	48%
Age class forest/clear	Clear cut, narrow strip	Norway spruce	Soil preparation natural	Chainsaw-tractor, harvester - forwarder	

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cut	15-30m		regeneration + artificial from plantation, type of seedling: balled and burlapped planting		
Age class forest/clear cut	Clear cut, strip 40-60 m or narrow strip 15-30 m	Common alder	Soil preparation natural + artificial from plantation, type of seedling: bare-rooted plant	Chainsaw - tractor, chainsaw - skidder	
Shelterwood	Shelterwood cutting	Scots pine, Norway spruce, Pedunculate oak, Beech	Soil preparation natural + artificial from plantation type of seedling: bare-rooted plant, balled and burlapped planting	Chainsaw - tractor, chainsaw - skidder	40%
Continuous cover forest		Norway spruce, Silver fir	Natural + artificial from plantation type of seedling: balled and burlapped planting	Chainsaw-tractor, chainsaw-skidder	3%
Sources: Silvicultural guideline - http://www.lasy.gov.pl/pl/pro/publikacje/copy_of_gospodarka-lesna/hodowla/zasady-hodowli-lasu-dokument-w-opracowaniu National Forest Inventory - http://www.buligl.pl/documents/10192/304500/WISL-2010-2014_en.pdf/9c32e9c7-911f-411f-af80-29e519a2574e					
Germany					
Key Silvicultural system	**Management system/options**	**Main tree species**	**Early operations**	**Employed harvesting systems**	**Covered forest area**
Age class forest, Continuous cover forest	Spruce forest type of the highlands	Norway spruce	Natural regeneration, plantation, stand establishment, opening-up, precommercial thinning	Harvester-forwarder, cut-to-length logging (CTL)	29%
Age class forest, Continuous cover	Mixed Spruce forest type of the highlands	Norway spruce, Fir, Beech, Maple,	Natural regeneration, stand establishment,	Harvester-forwarder, CTL, partly felling by chainsaw	

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forest		Larch, Pine	opening-up, precommercial thinning		
Age class forest, Continuous cover forest	Spruce forest type of the lowlands	Norway spruce	Plantation, stand establishment, opening-up, precommercial thinning	Harvester-forwarder, CTL	
Age class forest, Continuous cover forest	Pine forest / type of the lowlands	Pine	Soil preparation, plantation, stand establishment, opening-up, precommercial thinning	Harvester-forwarder, CTL	23%
Age class forest, Continuous cover forest	Pine forest / type of the highlands	Pine	Plantation, stand establishment, opening-up, precommercial thinning	Harvester-forwarder, CTL, partly felling by chainsaw	
Age class forest, Continuous cover forest	Beech conifer forest type	Beech, Spruce, fir, Douglas fir, Larch, Maple, Beech	Natural regeneration, additional plantation, stand establishment, opening-up, precommercial thinning	Chainsaw-skidder, partly big size harvester	17%
Age class forest, Continuous cover forest	Beech broadleaved forest type	Beech, Maple, Ash, Oak, Hornbeam	Natural regeneration, stand establishment, opening-up, precommercial thinning	Chainsaw-skidder, partly big size harvester	
Age class forest, Continuous cover forest	Oak broadleaved forest type	Oak, Lime, Hornbeam	Natural regeneration, plantation, stand establishment, opening-up, precommercial thinning	Chainsaw-skidder	9%
France					
Key Silvicultural system	**Management system/options**	**Main tree species**	**Early operations**	**Employed harvesting systems**	**Covered forest area ***

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Shelterwood	Beech high forest	Beech	Natural regeneration, thinnings	Chainsaw-forwarder	9%
Coppice / Coppice with standard	Beech coppice	Beech	Natural regeneration (where possible to take advantage of local genetic adaption), natural regeneration by coppicing	Chainsaw (harvester used sometimes for industrial timber), forwarder or skidder	
Coppice with standard	Pedunculate Oak (private forest)	Pedunculate Oak	Natural regeneration (where possible to take advantage of local genetic adaption), natural regeneration by coppicing	Chainsaw (harvester used sometimes for industrial timber), forwarder or skidder	21%
Coppice with standard	Sessile Oak (private forest)	Sessile Oak	Natural regeneration (where possible to take advantage of local genetic adaption)	Chainsaw-forwarder	
Shelterwood	Pedunculate Oak / Sessile Oak (public forest)	Pedunculate Oak / Sessile Oak	Natural regeneration (where possible to take advantage of local genetic adaption), natural regeneration by coppicing	Chainsaw (harvester used sometimes for industrial timber), forwarder or skidder	
Coppice	Pubescent oak coppice	Pubescent Oak	Natural regeneration by coppicing	Chainsaw-forwarder	9%
Coppice	Sweet chestnut coppice	Chestnut	Natural regeneration by coppicing	Harvester and Forwarder. Chainsaw used when the wood quality is very good.	5%
Coppice	Evergreen Oak coppice	Holm oak	Natural regeneration by coppicing, sometimes	Chainsaw (located usually in steep terrains) Forwarder, winch supported	4%

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			sowing		
Shelterwood	Ash (usually mixed stands)	Ash	Natural regeneration (where possible to take advantage of local genetic adaption), natural regeneration by coppicing	Chainsaw (harvester used sometimes for industrial timber), forwarder or skidder	4%
Coppice	Hornbeam coppice	Hornbeam	Natural regeneration by coppicing	Harvester and Forwarder	4%
Age class forest/clear cut	Poplars clearcut	Poplar	Soil preparation - full cleaning and ploughing (only in best cases), mulching, pruning	Chainsaw-forwarder (logs from 1,3m to 5m)/ harvester is used only when parcels have a lot of herbaceous vegetation	1%
Age class forest/clear cut	Maritime pine clearcut (private forest)	Maritime pine	Soil preparation (full or strip ploughing, discing), plantation, 3, -4 thinnings and clearings	Harvester and Forwarder (skidder for long trees)	7%
Age class forest/clear cut	Maritime pine clearcut/selection cut (public forest)	Maritime pine	Soil preparation (full ploughing, strip ploughing, discing, etc.), natural regeneration, thinnings	Harvester and Forwarder (skidder for long trees)	
Shelterwood	Scots pine mixed stands	Scots pine	Natural regeneration	Harvester and Forwarder (skidder for long trees)	6%
Age class forest/clear cut	Norway spruce planted	Norway spruce	Piling before plantation, 4 thinnings	Harvester and Forwarder	4%
Shelterwood/continuous cover forest	Norway spruce mixed stands (mountain)	Norway spruce	Natural regeneration, stand establishment, opening-up, precommercial thinning, thinnings	Chainsaw-skidder (gros bois, steep terrains)	
Clear-cut/shelterwood/cont	Silver fir mixed stands	Silver fir	Natural regeneration	Chainsaw-forwarder	4%

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inuous cover forest					
Age class forest/clear cut	Douglas fir clear cut	Douglas fir	Piling before plantation, 4 thinnings	Harvester and Forwarder (skidder for long trees)	3%
Age class forest/clear cut	Black pine clear cut	Black pine (laricio)	Piling before plantation, 4 thinnings	Harvester and Forwarder	1%
* Area where the species has the main forest canopy cover **Source:** National Forest Inventory - https://inventaire-forestier.ign.fr/					

Austria

Key Silvicultural system	Management system/options	Main tree species	Early operations	Employed harvesting systems	Covered forest area
Age class forest/clear cut	Spruce clear cut	Norway spruce		Chainsaw-cable yarder with processing unit, harvester-forwarder	50%
Continuous cover forest	Spruce-Fir-Beech forest	Norway spruce-Silver Fir-Beech		Chainsaw-skidder	10%
Shelterwood	Beech shelterwood	Beech		Chainsaw-skidder, harvester-forwarder	10%
Shelterwood	Oak shelterwood	Oak		Chainsaw-skidder, harvester-forwarder	2%
Sources: National Forest Inventory - http://bfw.ac.at/rz/wi.home					

Italy

Key Silvicultural system	Management system/options	Main tree species	Early operations	Employed harvesting systems	Covered forest area
Coppice	Coppice clear cut	Oak-Beech-Chestnut-Hornbeam-others	None	Chainsaw-mules; chainsaw-tractors with boxes; chainsaw tractor and trailer; chainsaw-excavator-forwarder; feller-buncher-forwarder; chainsaw-yarder	30%
Coppice	Coppice conversion	Oak-Beech-Chestnut-Hornbeam-others	First heavy thinning; following thinning operations until regeneration by shelterwood system or	Chainsaw-mules; chainsaw-tractors with boxes; chainsaw tractor and trailer; chainsaw-excavator-forwarder; feller-buncher-forwarder; chainsaw-yarder	10%

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			clearcut depending on species		
Shelterwood	Spruce-Fir-Beech forest	Spruce-Fir-Beech, generally mixed	Natural regeneration; ca. 2 thinning operations; preparation cut; seeding cut; removal cut	Chainsaw-skidder; harvester-forwarder; chainsaw-yarder; chainsaw-yarder-processor	10%
Age class forest	Spruce-Larch-forest /Gap cutting	Spruce-Larch-Pine (Scots and Mountain pine), pure or mixed	Natural regeneration; ca. 2 thinning operations; gap cut	Chainsaw-skidder; harvester-forwarder; chainsaw-yarder; chainsaw-yarder-processor	7%
Age class forest	Artificial pine forest /Gap cut - Clearcut	Austrian pine, Stone pine, Maritime pine	Manual planting, ca. 3 thinning operations, clearcut	Chainsaw-tractor; harvester-forwarder; feller-buncher-skidder	10%
Continuous cover forest	Spruce-Fir-Beech forest	Spruce-Fir-Beech, generally mixed	Natural regeneration; regular thinning of mature trees and dominated trees at 15-30 years intervals	Chainsaw-skidder; harvester-forwarder; chainsaw-yarder; chainsaw-yarder-processor	15%

Sources:

Third National Forest Inventory (2015) https://www.sian.it/inventarioforestale/
Bernetti G. (1995) Selvicoltura Speciale, UTET, Milano. 416 p.
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Spinelli R.; Magagnotti N.; Hartsough B. (2006) Raccolta integrata di tondame e biomassa nel taglio a gruppi di fustaie alpine, Italia Forestale e Montana 6, pp. 303-

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316.
Spinelli R., Magagnotti N., Dellagiacoma F. (2008) Meccanizzazione delle fustaie alpine: due diversi sistemi di lavoro. Sherwood: Foreste e Alberi Oggi 147, pp. 45-49

Spain

Key Silvicultural system	Management system/options	Main tree species	Early operations	Employed harvesting systems	Covered forest area
Continuous cover forest		*Quercus ilex* and *Quercus humilis*		Chainsaw-skidder, forwarder /chainsaw-horses hand forwarding	16.4% of forest area with tree cover (fcc> 5%) in Catalonia
50% Shelterwood / 50% Continuous forest cover		Scots pine		Chainsaw-skidder, forwarder, /chainsaw-horses	14%
Shelterwood		Aleppo pine	Tending		18%
Continuous cover forest		Black pine			7.80%
Coppice		*Castanea*, locally *Quercus ilex*		Chainsaw-skidder, forwarder	1% Castanea,
Plantation	Plantation with clearcut	Fast growing tree plantations: poplar, platanus, conifers (Douglas fir, silver fir, cedar)	Soil preparation/stand establishment	Chainsaw-skidder, forwarder	2%
Continuous cover forest		Silver fir, beech			2.50%
Tree-oriented Silviculture		Hardwood Quality timber (*Juglans, Prunus, Quercus robur/ petraea*)		Chainsaw-skidder, forwarder	

Sources:
http://cpf.gencat.cat/ca/cpf_03_linies_actuacio/cpf_transferencia_coneixement/cpf_projectes_europeus/

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3.2.2 Summary of key silvicultural systems by ecoregion

The summary of key silvicultural systems by European ecoregions (Figure 2) was created according to "State of Europe's Forest 2015" report and Tech4Effect questionnaire results.

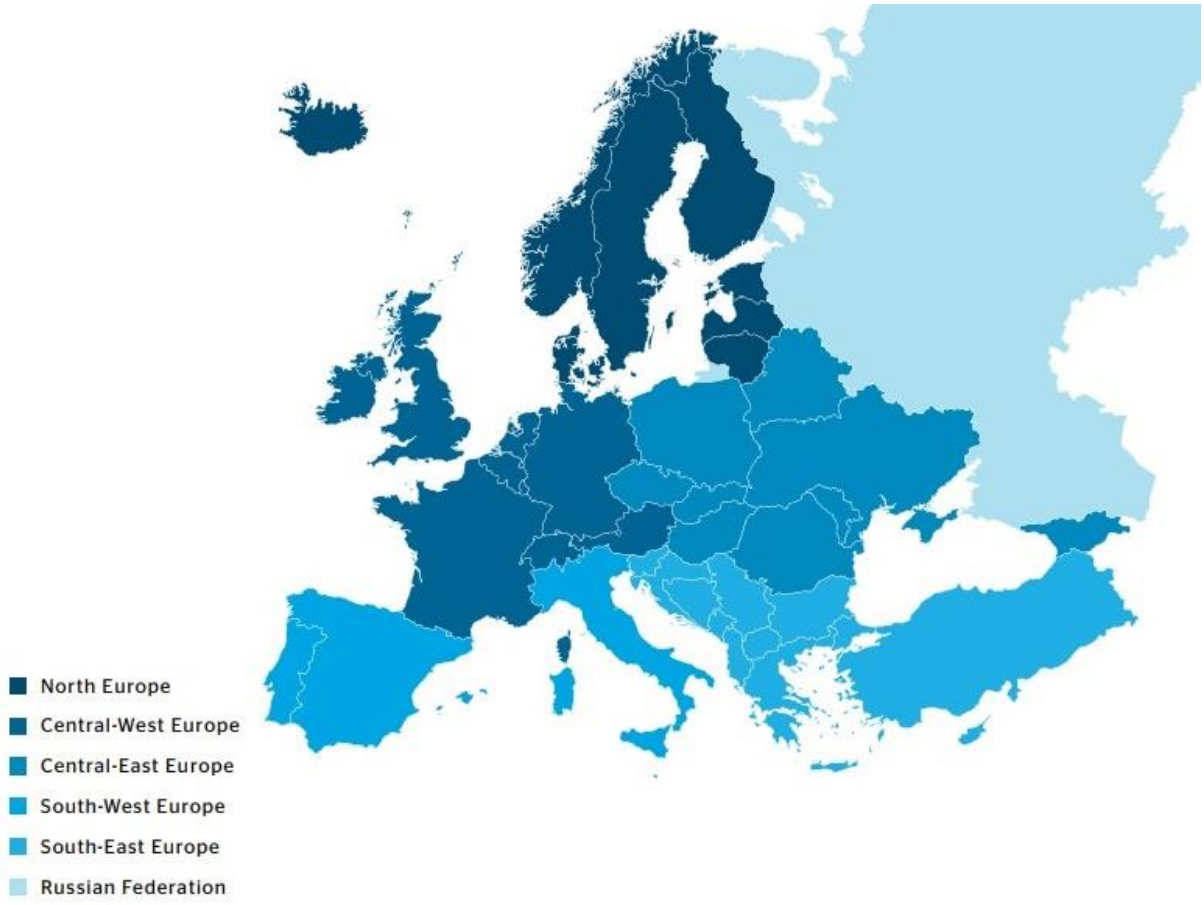

Figure 2. European forest ecoregions (source: http://www.foresteurope.org/docs/fullsoef2015.pdf).

North Europe

Main silvicultural system	Age class forest/clearcut
Main species	Scots pine, Norway spruce, Silver birch
Regeneration establishment and treatments	Soil preparation, natural regeneration, planting, weed control, thinning (2-3)
Main harvesting techniques	Harvester-forwarder (>90%), chainsaw-skidder

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Central-East Europe

Main silvicultural systems	Age class forest (clear cut, group cut), continuous cover forest, shelterwood
Main species	Scots pine, Norway spruce, Silver fir, Larch, Beech, Oak
Regeneration establishment and treatments	Soil preparation, natural regeneration, planting, tending, thinning (2-3)
Main harvesting techniques	Harvester-forwarder, chainsaw-skidder (tractor), chainsaw-cable yarder

Central-West Europe

Main silvicultural systems	Coppice, coppice with standard, age class forest / clear cut, shelterwood
Main species	Oak, Beech, Maritime pine, Scots pine, Norway spruce, Sitka spruce, Chestnut, Poplar, Douglas fir, Silver fir, Eucalyptus
Regeneration establishment and treatments	Soil preparation (ploughing), mulching, natural regeneration (by coppicing), planting, tending, thinning, pruning
Main harvesting techniques	Chainsaw-forwarder (skidder), Harvester-forwarder

South Europe

Main silvicultural systems	Coppice, shelterwood, age class forest (clear cut, gap cut), continuous cover forest, plantation
Main species	Oak, Beech, Chestnut, Hornbeam, Norway spruce, Pines (various: austrian, scots, maritime and umbrella the main ones), Hybrid poplar
Regeneration establishment and treatments	Soil preparation, natural regeneration, tending, thinning (2-3), pruning (hybrid poplar)
Main harvesting techniques	Chainsaw-mules, chainsaw-tractor, chainsaw-tractor, skidder or forwarder, feller-buncher-forwarder, harvester-forwarder, chain saw-yarder

The method of regenerating a forest stand after final harvest is one of the crucial issues for current and long-term forest sustainability. For comparative purposes a general overview on various practices by European ecoregions is provided in

Table 3. However, it should be noticed that these mean numbers underscore sharp differences at the local level and can change dramatically from Country to Country. In Italy, for instance, the proportion of forest area under coppice management amounts to 42%, i.e. 10 times as much as the average for South-West Europe.

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Table 3 Share of forest area (uneven-aged and even-aged) by regeneration types in the European regions, 2010 (source: http://www.foresteurope.org/docs/fullsoef2015.pdf).

SOEF Region	Natural regeneration and natural expansion		Afforestation and regeneration by planting and seeding		Coppicing	
	million ha	% of forest area	million ha	% of forest area	1000 ha	% of forest area
North Europe	48.4	68	22.4	32	n.s.	0
Central-West Europe	22.3	64	10.6	30	2.0	6
Central-East Europe	16.1	52	13.0	42	2.1	7
South-West Europe	26.1	86	3.3	11	1.1	4
South-East Europe	19.9	72	4.0	14	3.6	13
Europe	132.8	68	53.2	27	8.8	5
EU 28	98.5	68	38.8	27	5.4	5

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4 Potentials for enhancing wood production

4.1 List of options by country

The potentials for enhancing wood production for different European countries were determined based on Tech4Effect questionnaire results (Table 4):

Table 4 Questionnaire - Options to enhance productivity by country

Country	Anticipated options to enhance productivity
Finland	• **Options for all listed silvicultural systems:** continuous mounding machines; reduction of seasonal variation of workload; systems assisting and guiding the operator; simplified forwarding operations; larger harvesting units (area).
Norway	• **Options for all age-class/ clearcut systems:** Improved stand density management strategies which includes: 1) appropriate initial planting densities, 2) increased amount of early stand tending's with guidelines on timing of tending and residual stand density, and 3) increased amount of mid-rotation thinning with guidelines on timing and residual stand density.
Denmark	• **Coppice:** Use of other tree species than poplar e.g. fast growing conifers; extending rotation age; regeneration by planting with regular intervals; coppicing is not an option; design of stand and forest infra structure; improved instructions; since management decisions at time may affect the productivity over time the time dimension needs to be addressed; technical efficiency achieved by high harvesting rates may contribute to high performance but compromise long term productivity and economic outcome. • **Even aged high forest (monocultures as well as mixed stands. Rotation ages 40-150 years):** Improved instructions; improved stand and forest infrastructure; thinnings: marking of trees for thinning and or later marking of future trees; power cultures - forced quality broadleaves (with high productivity rates in early stage of life cycle such as: *Acer pseudoplatanus, Prunus avium, Quercus spp., Fraxinus excelsior, Juglans spp.* with intensive management regime including pruning in order to produce high quality crop trees)- no thinning (optional in e.g. *Picea sitchensis* and *Abies grandis*) • **Even aged high forest (Beech shelter wood. Regeneration time up to 20 years):** Improved instructions; improved stand and forest infrastructure; marking of trees for thinning and or future trees - establishment of semi-permanent skidding roads. • **High forest (typically mixed stands. Becoming more common):** Improved instructions; improved stand and forest infrastructure; permanent skidding roads.
Poland	• **Clearcut:** Systems assisting and guiding the operator; mechanize harvesting and processing; optimize trail network to reduce damage at trees. • **Shelterwood/Continuous cover forest:** Mechanize harvesting and

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	processing; optimize trail network to reduce damage at trees.
Germany	• **Options for all listed silvicultural systems:** Opening-up; aligned harvesting techniques.
France	• **All broadleaves:** the main challenge in France is to increase mechanization of broadleaves with irregular shapes and very heterogeneous size as this resource is immobilized for decades. • **Mountain forest:** Many stands resulting from farming land abandonment or plantation for erosion prevention on steep terrain remain unused and is poorly managed and difficult to harvest. Use of appropriate machinery and active management is a way to increase productivity in these areas. • **Poplars clearcut:** Prunings are made not to enhance the productivity but to enhance the quality of the wood, then it will be better payed by the industrials, it improves profitability. Selection of the more pest resistant collection of clones is favoring production • **Pedunculate Oak coppice/Sessile Oak coppice/Pubescent oak coppice/Evergreen Oak coppice/Hornbeam coppice/Sweet chestnut coppice:** Some coppices can be very old (hundreds of years) or located in place not any more appropriate under changing climate. Regeneration with new material or enrichment and/or replacement by plantation is an option to increase productivity (for wood and fruits) • **Pedunculate Oak and Sessile Oak shelterwood:** The ONF (National Forest Office) applies active thinning regimes to enhance the wood production. • **Ash (usually mixed stands):** Big problem with dieback because of the *Hymenoscyphus fraxineus* (Chalara fraxinea) fungus, forest owners stopped investing in this species. • **Maritime pine clearcut:** Pruning is highly recommended when producing high wood quality to increase profitability, but not rewarded at the moment. Used of improved material with shorter rotation period is a way to increase productivity in a system already requiring active .management. Some alternative thinning regime with high initial density and first thinning for biomass are considered to increase productivity. Additional resource for biomass use is more and more commonly harvested: stumps, branches. • **Scots pine mixed stands/Norway spruce mixed stands (mountain)/Black pine clearcut:** Limited management, the main challenge is to mechanize and renew old stand established for soil erosion protection but with a potential for timber. • **Douglas fir clearcut:** Sometimes there is a first thinning at the early plantation begging for enhancing the growth, Douglas fir wouldn't lose its mechanical properties. Pruning after the first thinning and another pruning when height is about 12 m (ideal cases) is a common way to increase profitability. Use of provenance adapted to drought is an appropriate way to increase productivity of lower stand suffering under climate change.
Austria	• **Shelterwood (Beech, Oak):** Reduce rotation period to permit harvester use,

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	introduce non-native conifers to enhance share of sawn logs. • **Clearcut (Spruce):** Large tree spacing to increase efficiency of thinning. • **Continuous cover forest (Spruce-Fir-Beech):** Optimize trail network to reduce damage at trees.
Italy	• **Coppice:** Mechanized or semi-mechanized whole-tree harvesting for biomass production, rather than short-wood harvesting for firewood production. • **Spruce-Fir-Beech Continuous cover forest (continuous cover management, shelterwood cut)/Spruce-Larch-Pine even-age forest (gap cutting):** Mechanized harvesting and processing by introducing state-of-the-art cut-to-length logging technology (mechanized harvesting system in which trees are delimbed and cut to length directly at the stump); improve and automate yarding; effective biomass recovery. • **Artificial pine forest:** Increase mechanization of operation, by introducing mechanized cut-to-length logging and whole-tree harvesting technology.
Spain	• ***Quercus ilex* and *Quercus humilis*:** Use of skidding roads. • ***Pinus sylvestris*:** Application of tending and thinning on time. Timber quality classification on site and on-industry; apply ORGEST silvicultural models. • **Hardwood quality timber (*Juglans, Prunus, Quercus robur, Quercus petraea*...):** Increase the use of this silviculture in mixed stands.

4.2 Summary of mentioned options for enhancing wood production

Within the variety of listed options for efficiency increase, we can identify a number of recurring issues.

Issues regarding **silvicultural activities**:

- Tending and thinning: Effective and careful pre-commercial thinning; adaption of thinning regime by tree species (e.g. more thinning on Oak, no thinning on Sitka spruce, Giant fir, possibly Douglas fir and mixed stands)
- Change of species (including non-natives?)
- Selection of appropriate provenances
- Adaption of thinning regime: more thinning on particular species, e.g. Oak, no thinning on particular species, e.g. Sitka spruce, Giant fir, possibly Douglas fir
- Change of rotation period: reduction in high forest (→ compatibility with mechanized harvesting techniques), extension in coppice (compatibly with the regeneration potential of the stumps)
- Genetic improvement of seedlings, high productivity clones
- Effective site preparation (drainage, ploughing)
- Effective and careful pre-commercial thinning and weed control

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- Facilitation of N fixing understorey
- Forest fertilization on appropriate stands (applying strict economic and ecological criteria)

Issues regarding **harvesting activities**:

- Establishment of appropriate skidder trail networks (= corridor layout) and appropriate stand infrastructure (e.g. suitable size of harvesting unit)
- Enhanced mechanization of harvesting, processing and yarding procedures
- Promotion of tree marking for precommercial thinning in even aged high forest, development of supportive tools for tree selection done by harvester operator
- Selection of most favorable harvesting period (season), in combination with the selection of most favorable harvesting technique, in order to reduce soil and stand damages
- Effective biomass recovery all over Europe (e.g. whole tree method in coppice)

Other UR projects about similar topics:

FORMIT - FORest management strategies to enhance the MITigation potential of European forests. Seventh Framework Programme

- Develop forest management scenarios for carbon sequestration in Europe, including mitigation measures and management strategies for different regions, and accounting for trade-offs with other forest functions.
- Insights into options for carbon storage in forests accounting for historical management practices, regional differences, and management scenarios and modes of operation.

WOODVALUE - Value creation in wood supply chains. WoodWisdom-Net

- standardized methodology at European level to define, measure and value the efficiency and profitability of key wood supply chains
- Methods to optimize wood allocation problem

WOODAPPS - Improvement in collaboration along the wood value chain through knowledge-based methods and mobile applications. WoodWisdom-net, ERA – NET Bioenergy.

- sustainability and competitiveness of the European forest-based sector as well as to promote the utilization of cutting edge knowledge and technology in new applications
- link between the forestry, wood industry and the rapid growing, cutting-edge and Information and Communication Technology sector

SIMWOOD – sustainable innovative mobilization of wood - SIMWOOD is a four-year EU FP7-KBBE collaborative project. The project runs from November 2013 until October 2017 (http://www.simwood.efi.int/about-the-project.html). It provides

- A structured framework to analyze barriers and leviers to facilitate mobilization
- An example of diagnostic on projects regions
- A set of solutions implemented on demonstration areas
- An online tools to follow past and ongoing initiative to support wood mobilization in Europe: https://simwood.jrc.ec.europa.eu/

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