D4.2 Report on pilot case study 2

***MAIL**: Identifying Marginal Lands in Europe and strengthening their contribution potentialities in a CO2 sequestration strategy*

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ABBREVIATIONS

Term	Explanation
AGB	Above-Ground Biomass
BCEF	Biomass Conversion and Expansion Factor
BGB	Below-Ground Biomass
C	Carbon
DBH	Diameter at breast height
Dg	Mean square diameter
DG	Stand mean diameter
ESA	European Space Agency
G	Basal area
GIS	Geographic Information System
H	Height of the forest stand
H0	Dominant stand height
Hm	Stand mean height
HO	Stand top height (height of the base center trunk of the 100 strongest trunks/ha)
IPCC	Intergovernmental Panel on Climate Change
MFE50	Mapa Forestal Español Escala 1:50.000
MLs	Marginal Lands
N	Forest stand density
NASA	National Aeronautics and Space Administration
SI	Site Index
UNFCCC	United Nations Framework Convention on Climate Change

V	stand tree wood volume
VB	Stand tree wood volume per hectare in m^3
VD	Stand solid wood volume per hectare in m^3
VS	Stand timber volume per hectare in m^3

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EXECUTIVE SUMMARY

The assessment of carbon sequestration capacity is necessary to evaluate how proposed afforestation strategies may be beneficial as carbon sinks. Eight test sites from four countries (Germany, Poland, Spain and Greece) were analysed and used as show cases to present to potential of marginal lands in details. In the first step, data about dominant species and their characteristics were gathered. Next, for each test site, the dominant species were identified, and for them the optimal biomass and carbon estimation method was selected. Simulations of potential forest properties were realized using yield tables as prediction for future (from 20 to 140 years).

Carbon sequestration capacity estimates for test sites using mixtures of dominant species were prepared for ~50 years into the future.

1 INTRODUCTION

The main objective of the ***MAIL*** project is to increase the utilization of the MLs as carbon sinks by the agricultural and forestry related sectors. To achieve this, the ***MAIL*** project focuses on the development of innovative methods and tools (Web GIS/ web platform) for the identification of MLs based on open source and free satellite data, as well as fully consistent carbon sequestration calculation methodologies with the guidelines published by the IPCC and aligned with the UNFCCC carbon emission reporting requirements. This document is scoped under the work package 4 (WP4) of the ***MAIL*** project, which focuses on pilot cases studies and aims:

- To define the best methods to map and monitor the MLs based on open-source data and open-source applications
- To estimate carbon stock in forest products
- And to validate the methodologies and procedures defined in work package 2

Aligned with the aforementioned goals, in this task we will assess the quantification of carbon sequestration capacity in MLs based on the following objectives:

- To determine the land cover and land use of the area of interest
- To integrate the environmental limitations in the analysis of the MLs
- To evaluate the status of the existing biomass stock at the area of interest
- To quantify the carbon sequestration capacity in the MLS

As a starting point, the methods and calculations proposed in this document are based in the outputs of the previous deliverables of this project concerning (1) the definition of the MLs in deliverable 2.1. D2.1 presents a coherent theoretical description of MLs under ***MAIL*** scope considering the three major drivers for marginality: environmental factors, socioeconomic factors, and cultural factors. (2) The available data at European level described in deliverable 2.2, (3) the proposed methodology for MLs identification (deliverable 2.3), and the carbon sequestration models reviewed in deliverable 2.5. The outputs of this task will help develop the MLs classification in carbon sequestration capacity groups.

2 DATA ACQUISITION

Several data sources are required to analyze the carbon sequestration capacity. The main information needed is a description of the forest in an area that can relate to the marginal land. This information can be obtained from traditional yield tables for low-quality sites.

2.1 Forest inventories for species selection

Forest inventory or biodiversity databases were consulted to evaluate the main species present in the pilot sites. The most present species in the ML surrounding forest areas will be proposed as the suitable ones for the reforestation of the marginal lands and the estimation of future carbon sequestration. Therefore, the most updated or accurate sources of information were assessed to propose a detailed species selection. The sources consulted were:

- ***Spanish*** national forest map 1:50,000 (MFE50): This layer identifies the location of the forests in Spain and attaches a hierarchical classification of land uses, focusing on the forest classes, especially in the wooded ones. The map includes information of the three main species present in the stand/forest coded following the National forest inventory nomenclature, forest structure, area occupied by species in the stand, canopy cover fraction, and the state of development of the stands. The map was created during 1998 and 2007. The layer can be found in the Ministery for Ecological Transition.
- ***Greece.*** The species selection in the Greek pilot sites was performed using the information provided by two forest inventories carried out in 2007 in the Isenli forest. The forest inventory consists of 45 plots, where 25 are rectangular plots with an area of 0.1 ha and 20 plots correspond to an older inventory (Kossenakis, 1939) which does not provide species composition but forest type. From the inventory, we learn the species composition by hectare for the 25 rectangular plots (the older plots do not contain this information).
- In ***Poland***, databases available in Forest Data Bank have been used. It contains inter alia information about species, density, mixture, site type, site class, volume, and data state year.
- Third ***German*** forest inventory: The German forest inventory is a legal mandate registered in the German Forest Law in Article 41a. German forests are inventoried every ten years being the first inventory executed in the period 1986-1988, the second one 2001/2002, and the third one in 2011/2012. The data is extracted from more than 60,000 sampling points scattered all around the country where more than 420,000 trees

are measured. The inventory offers information about forest area and changes over time, the growing wood stock and variation, the timber harvest, deadwood stock and variation, the species composition and forest diversity, carbon stock. Al the information and data of the German forest inventory is available at Dritte Bundeswaldinventur.

Table 1. Summary of the main species selected for each country with test areas.

Country	Species	Source
Germany	*Pinus sylvestris* L. Orlova *Picea abies* Link	National Forest Inventory
Poland	*Pinus sylvestris* L. Orlova *Quercus species*	Polish National Forest Inventory / Forest Data Bank
Spain	*Pinus pinaster* Aiton *Pinus nigra* J.F.Arnold *Pinus sylvestris* L. Orlova *Pinus halepensis* Mill.	Spanish Forest Map 1:50 000
Greece	*Pinus halepensis* Mill. *Quercus species*	Inventory of the test sites

2.2 Yield tables

The traditional forestry tools to describe different stages of a monospecific forest stand are the yield tables. These tables provide both variables that explain the structure of the forest stand and yield in terms of stem volume over time and for a given forest management plan that includes silvicultural treatments for a selected species. Every row entry in the yield table represents either an age (or a diametric class) for which the following information is typically provided:

- ***N***: *stand density* or number of trees present in the stand.
- ***H***: *height of the stand*, can either be represented by the dominant height (height of the 100 trees holding the biggest diameter) or mean height. Unit: meters
- ***G***: *Basal area*. Cross-section area for all the trees at 1.3 meters' height. Unit: m^2
- ***V***: Stem *volume* with bark. Unit: dm^3

Yield tables are statistical models based on empirical data that relate the yield production with a volume equation that is dependent on one (single entry table) or two variables (double-entry table), frequently the diameter at breast height and dominant height. The output of these models is a table showing the yield in terms of stem volume for the different ages of a stand, hence the name (Bravo et al., 2012). Besides, yield tables are linked to silvicultural interventions (such as thinning) where the volume of extracted wood is quantified, and the final status of the stand is presented.

A more modern approach to project and estimate growth in a forest stand is applying growth and yield models. Models differ essentially from yield tables in the number of variables used for explaining the target variables and the more complex statistical analysis involved. For example, to perform simulations closer to reality, models can include predictions on mortality rate, ingrowth, competence using as input data forest inventory. The more variables and equations to explain the behavior of the forest, the more complex the model results (Bravo et al., 2012).

For the development of the task both options were considered as a valid source to predict the structure of the modules. Although old-fashioned, the yield tables stand out for their easy readability and being ready to use. On the other hand, models offer higher accuracies, however, they are not often available or already implemented in software or user-friendly interface. Most of the growth models are fitted local or regional scopes or are harder to implement. Therefore, models were not implemented as their implementation was constrained by inventory data availability. This limitation arises from the definition of ML created in task 2.1. which states that MLs do not present arboreal vegetation, where there is no forest inventory data. At this point, the methodology assumes that the forest inventory data used for the MLs will correspond with low site index areas, except those areas where marginality is not originated by environmental constraints, but social.

2.2.1 Germany

In Germany, the latest available yield tables were obtained for the species selected: Pinus sylvestris and Picea abies. For Pinus sylvestris we used the yield tables from (Lembcke et al., 1975). The yield tables are based on very large dynamic data and long-term observed test areas. The data was biometrically well represented and allowed for the creation of yield tables classified in several levels of yield and for different silvicultural treatments. An analysis performed on the yield parameters at all levels of nutrient components, hydric balance, macroclimatic levels from northwestern Germany showed that the Pinus sylvestris yield tables were representative of the states of Brandenburg, Mecklenburg-Western Pomerania, and Saxony-Anhalt (Lembcke et al., 1975). For the marginal lands, the yield tables corresponding to the lowest levels of yield and with moderate thinning were selected as, typically lower intensities in silvicultural treatment are aimed for conservation goals whereas high intensities typically target and increase on the yield at the final cut (del Río et al., 2006), (Montero et al., 2001), (Lembcke et al., 1975), (García Abejón J.L., 1981).Additionally, yield tables with average production levels were selected for the less marginal lands (type 1). The yield tables selected were presented in Table 2,

Table 3,

Table 4, and Table 5, where *A* is the stand age in years, *HG* is the stand mean height (base area mean height) in meters, *HO* is the stand top height (height of the base center trunk of the 100 strongest trunks/ha) in meters), *G* is the basal area in m^2, *DG* is the stand mean diameter (diameter of the base area mean stem) in cm, *N* is the number of trees per hectare, *VS* in the stand timber volume per hectare in m^3, *VD* in the stand solid wood volume per hectare in m^3, and *VB* stand tree wood volume per hectare in m^3.

Table 2. Scots pine (*Pinus sylvestris*) yield table. Lower yield level Medium high creditworthiness 18 tillering degree 0.95 (*U 18 (III, 5) - 0.95 Unteres Ertragsniveau Mittelhöhenbonität 18 Bestockungsgrad 0,95).*

Remaining inventory								
Age	**HG**	**HO**	**G**	**DG**	**N**	**VS**	**VD**	**VB**
years	*m*	*m*	*m²*	*cm*	*trees/ha*	*m³*	*m³*	*m³*
30	6.6	7.8	19.4	5.8	7,317	70	20	123
35	7.7	9	21.2	7.3	5,129	88	43	129
40	8.8	10.1	22.8	8.8	3,754	106	72	141
45	9.9	11.2	24.1	10.4	2,850	123	99	155
50	10.9	12.2	25.3	12	2,233	140	122	171
55	11.8	13.1	26.2	13.6	1,795	155	142	186
60	12.7	14	27	15.3	1,476	170	160	202
65	13.6	14.8	27.7	16.9	1,236	183	177	217
70	14.3	15.5	28.2	18.5	1,052	196	191	230
75	15.1	16.2	28.6	20	908	207	204	243
80	15.8	16.9	28.9	21.6	793	217	216	255
85	16.4	17.5	29.2	23	700	226	226	265
90	17	18	29.3	24.5	623	234	235	274
95	17.5	18.5	29.4	25.9	560	241	242	282
100	18	18.9	29.5	27.2	507	247	249	289
105	18.4	19.3	29.5	28.5	462	252	256	295
110	18.8	19.6	29.4	29.7	424	256	261	299
115	19.1	19.9	29.3	30.9	391	259	264	303
120	19.4	20.2	29.2	32	362	261	267	306
125	19.7	20.4	29.1	33.1	338	262	269	307
130	19.9	20.6	28.9	34.1	316	262	270	308
135	20	20.7	28.7	35.1	297	262	271	308
140	20.1	20.8	28.5	36	280	261	270	307

Table 3. Scots pine (*Pinus sylvestris*) yield table. Lower yield level Medium high creditworthiness 20 tillering degree 0.95. *(U 20 (III, 0) - 0.95 Unteres Ertragsniveau Mittelhöhenbonität 20 Bestockungsgrad 0,95).*

Remaining inventory								
A	HG	HO	G	DG	N	VS	VD	VB
years	*m*	*m*	*m²*	*cm*	*trees/ha*	*m³*	*m³*	*m³*
30	7.7	9	20.8	6.9	5,629	86	39	129
35	8.9	10.3	22.7	8.5	4,036	107	70	143
40	10.2	11.5	24.3	10.1	3,011	127	101	160
45	11.3	12.7	25.7	11.9	2,322	147	128	178
50	12.4	13.7	26.9	13.6	1,843	166	152	197
55	13.4	14.7	27.8	15.4	1,498	183	173	215
60	14.4	15.7	28.6	17.1	1,243	200	192	233
65	15.3	16.5	29.3	18.8	1,050	215	210	249
70	16.1	17.3	29.8	20.5	900	229	225	265
75	16.9	18	30.2	22.2	782	241	239	279
80	17.6	18.7	30.5	23.8	686	252	252	292
85	18.3	19.3	30.7	25.4	609	262	262	303
90	18.9	19.9	30.9	26.9	545	271	272	313
95	19.5	20.4	31	28.3	492	278	282	322
100	20	20.9	31	29.7	447	285	289	329
105	20.5	21.3	31	31.1	409	290	295	335
110	20.9	21.7	31	32.4	377	294	300	340
115	21.2	22	30.9	33.6	349	297	304	344
120	21.5	22.3	30.7	34.7	324	300	307	347
125	21.8	22.5	30.6	35.8	303	301	309	348
130	22	22.7	30.4	36.9	285	301	310	349
135	22.2	22.8	30.2	37.8	269	301	311	349
140	22.3	22.9	30	38.8	254	300	310	348

Table 4. Scots pine (*Pinus sylvestris*) yield table. Average yield medium-high creditworthiness 18 tillering degree 1.0. (*U 18 (III, 5) - 1.0 Mittleres Ertragsniveau Mittelhöhenbonität 18 Bestockungsgrad 1.0*).

Remaining inventory								
Age	HG	HO	G	DG	N	VS	VD	VB
years	*m*	*m*	*m²*	*cm*	*Trees/ha*	*m³*	*m³*	*m³*
30	6.6	7.9	20.4	5.5	8,613	74	18	135
35	7.7	9.1	22.3	6.9	6,009	93	42	139
40	8.8	10.2	24	8.3	4,384	111	71	150
45	9.9	11.3	25.4	9.9	3,320	130	101	165
50	11	12.3	26.6	11.4	2,596	147	126	180
55	12	13.2	27.6	13	2,084	164	148	196
60	13	14	28.4	14.5	1,711	179	167	212
65	14	14.9	29.1	16.1	1,432	193	185	227

Remaining inventory								
Age	**HG**	**HO**	**G**	**DG**	**N**	**VS**	**VD**	**VB**
years	*m*	*m*	*m²*	*cm*	*Trees/ha*	*m³*	*m³*	*m³*
70	14	15.6	29.7	17.6	1,218	207	200	242
75	15	16.3	30.1	19.1	1,050	218	214	255
80	16	16.9	30.4	20.6	917	229	226	267
85	16	17.5	30.7	22	809	239	237	278
90	17	18.1	30.9	23.4	721	247	246	287
95	18	18.5	31	24.7	647	254	255	296
100	18	19	31	26	586	260	261	303
105	18	19.4	31	27.2	534	265	267	309
110	19	19.7	31	28.4	490	270	274	314
115	19	20	30.9	29.5	451	273	277	318
120	19	20.3	30.8	30.6	419	275	280	321
125	20	20.5	30.6	31.6	390	276	282	322
130	20	20.6	30.4	32.6	365	276	283	323
135	20	20.8	30.2	33.5	343	276	284	323
140	20	20.8	30	34.3	324	275	283	322

Table 5. Scots pine (*Pinus sylvestris*) yield table. Average yield medium-height creditworthiness 20 tillering degree 1.0. (*U 20 (III, 0) - 1.0 Mittleres Ertragsniveau Mittelhöhenbonität 20 Bestockungsgrad 1.0*).

Remaining inventory								
Age	**HG**	**HO**	**G**	**DG**	**N**	**VS**	**VD**	**VB**
years	*m*	*m*	*m²*	*cm*	*trees/ha*	*m³*	*m³*	*m³*
30	7.7	9	21.9	6.6	6,460	90	38	139
35	8.9	10.4	23.9	8.1	4,616	112	70	152
40	10	11.6	25.6	9.7	3,435	134	103	169
45	11	12.7	27.1	11.4	2,645	155	133	188
50	12	13.8	28.3	13.1	2,096	175	158	207
55	13	14.8	29.3	14.8	1,702	193	181	226
60	14	15.7	30.1	16.5	1,411	210	202	244
65	15	16.6	30.8	18.2	1,191	226	220	262
70	16	17.4	31.4	19.8	1,020	241	236	278
75	17	18.1	31.8	21.4	885	254	251	293
80	18	18.8	32.1	22.9	777	266	264	306
85	18	19.4	32.4	24.4	690	276	276	318
90	19	20	32.5	25.9	617	286	286	328
95	20	20.5	32.6	27.3	557	293	295	338
100	20	20.9	32.7	28.7	506	300	304	345
105	21	21.4	32.6	30	463	306	310	352
110	21	21.7	32.6	31.2	426	310	315	357
115	21	22	32.5	32.4	394	313	319	361
120	22	22.3	32.4	33.5	367	316	322	364

Remaining inventory								
Age	**HG**	**HO**	**G**	**DG**	**N**	**VS**	**VD**	**VB**
years	*m*	*m*	*m²*	*cm*	*trees/ha*	*m³*	*m³*	*m³*
125	22	22.6	32.2	34.6	343	317	324	366
130	22	22.7	32	35.6	322	318	326	367
135	22	22.9	31.8	36.5	304	317	326	367
140	22	23	31.6	37.4	288	316	326	366

The Picea abies yield tables were extracted from (Schober, 1975). In this publication, yield tables for 17 German forest species are compiled from different authors. The forest species considered in the document are *Quercus robur, Quercus rubra, Fagus sylvatica, Dalbergia melanoxylon, Fraxinus excelsior, Betula sp., Robinia sp., Populus sp., Picea Abies, Picea sitchensis, Pseudotsuga menziesii, Crataegus sp., Pinus sylvestris, Pinus strobus, Larix decidua*, Larix kaempferi. Wiedemann defined 2 regimes of management for Picea abies: one of medium intensity or intermediate profit (mässige Starke) and another one with staggered intervention scheme (gestaffelte duchforstung). Both yield tables were developed in 1936 with an update of the moderate regime in 1942. Despite their antiquity, these yield tables were chosen as no more recent yield tables/growth models could be found for this species in Germany. The yield tables selected were presented in Table 6,

Table 7, Table 8, and Table 9, where *A* is the stand age in years, *HG* is the stand mean height (base area mean height) in meters, *HO* is the stand top height (height of the base center trunk of the 100 strongest trunks/ha) in meters, *DG* is the stand mean diameter (diameter of the base area mean stem) in cm, *N* is the number of trees per hectare, and *V* is the stand tree wood volume per hectare in m^3.

Table 6. Norway spruce (*Picea abies*) yield table. Moderate thinning class 5 (lowest production) *(Fichte Mässige V.Ertrags).*

Remaining inventory					
A	**HG**	**HO**	**DG**	**N**	**V**
years	*m*	*m*	*cm*	*trees/ha*	*fm*
40	4.5	5.2	6.8	4,880	17
45	5.6	6.7	7.7	4,345	39
50	6.8	8.3	8.5	3,795	64
55	8	9.8	9.4	3,350	90
60	9.3	11.3	10.3	2,965	117
65	10.5	12.7	11.2	2,630	145

Remaining inventory					
A	**HG**	**HO**	**DG**	**N**	**V**
years	*m*	*m*	*cm*	*trees/ha*	*fm*
70	11.7	14	12.1	2,335	170
75	12.8	15.2	12.9	2,100	191
80	13.8	16.2	13.7	1,900	208
85	14.8	17.3	14.4	1,738	221
90	15.7	18.2	15	1,578	231
95	16.5	19	15.7	1,442	239
100	17.2	19.7	16.3	1,325	245

Table 7. Norway spruce (*Picea abies*) yield table. Moderate thinning class 4 (low production). *(Fichte Mässige IV.Ertrags).*

Remaining inventory					
A	**HG**	**HO**	**DG**	**N**	**V**
years	*m*	*m*	*cm*	*trees/ha*	*fm*
30	4.2	4.7	6.3	5,917	-
35	5.5	6.6	7.2	4,718	22
40	6.9	8.4	8.3	3,870	54
45	8.3	10.1	9.4	3,370	91
50	9.8	11.9	10.6	2,977	129
55	11.3	13.6	11.7	2,635	167
60	12.7	15.1	12.8	2,355	203
65	14	16.5	13.8	2,097	234
70	15.2	17.7	14.9	1,862	261
75	16.3	18.9	15.9	1,670	284
80	17.3	19.9	16.8	1,509	304
85	18.3	20.9	17.8	1,365	321
90	19.2	21.7	18.7	1,232	335
95	20.1	22.6	19.5	1,120	348
100	21	23.5	20.4	1,023	360
105	21.8	24.2	21.2	942	368
110	22.6	25	21.9	867	376
115	23.3	25.6	22.6	800	375
120	24	26.3	23.2	735	373

Table 8. Norway spruce (*Picea abies*) yield table. Staggered thinning class 3 (lowest production) (*Fichte Gestaffelte Durchforstung III.Ertrags*).

Remaining inventory					
A	**HG**	**HO**	**DG**	**N**	**V**
years	*m*	*m*	*cm*	*trees/ha*	*fm*
20	3.7	3.8	4.1	5,917	-
25	5.5	6.5	6.1	4,617	1
30	7	8.4	7.8	3,667	35
35	8.6	10.3	9.5	2,887	72
40	10	11.9	11	2,392	111
45	12.1	14.2	12.6	2,002	152
50	13.9	16.1	14.3	1,692	194
55	15.5	17.7	15.9	1,454	233
60	17	19.3	17.5	1,266	269
65	18.4	20.6	19.1	1,110	302
70	19.6	21.8	20.6	984	331
75	20.7	22.9	22.1	879	356
80	21.8	23.9	23.5	791	378
85	22.8	24.9	24.9	715	397
90	23.7	25.7	26.2	649	415
95	24.5	26.4	27.6	590	431
100	25.4	27.3	29	539	446
105	26.3	28.1	30.4	494	460
110	27.1	28.8	31.8	453	472
115	27.7	29.4	33.2	417	480
120	28.3	29.9	34.6	384	488

Table 9. Norway spruce (*Picea abies*) yield table. Staggered thinning class 2 (low production) (*Fichte Gestaffelte Durchforstung II*).

Remaining inventory					
A	**HG**	**HO**	**DG**	**N**	**V**
years	*m*	*m*	*cm*	*trees/ha*	*fm*
20	4.9	5.6	5.2	5,917	-
25	7.2	8.6	7.8	3,594	33
30	9.2	11	10	2,794	86
35	11.4	13.4	11.9	2,204	133
40	13.7	15.8	13.7	1,795	183
45	15.8	18	15.5	1,517	235
50	17.9	20.2	17.3	1,303	287
55	19.8	22.1	19.1	1,127	334
60	21.5	23.7	20.9	987	377
65	23	25.2	22.7	867	414
70	24.2	26.3	24.6	760	443
75	25.3	27.3	26.3	678	469
80	26.3	28.3	28.1	610	491

Remaining inventory					
A	HG	HO	DG	N	V
years	*m*	*m*	*cm*	*trees/ha*	*fm*
85	27.3	29.2	29.7	553	511
90	28.4	30.2	31.4	501	529
95	29.2	30.9	33.1	456	545
100	30.1	31.8	34.8	416	559
105	30.9	32.5	36.5	379	572
110	31.6	33.1	38.1	350	584
115	32.1	33.5	39.7	325	595
120	32.6	33.9	41.3	302	605

2.2.2 Poland

Yield tables used in the case of the Polish test site were published in 2001 (Szymkiewicz, 2001) and contain information about 10 species (merging information from various sources). The species selected for this test site are the *Pinus sylvestris* and *Quercus species*. For each of them several classes are available and two types of treatment (weak and strong). For biomass and carbon estimations, weak treatment and 2 worst classes have been selected. Class IV and V for *Pinus sylvestris* and class III and IV for *Quercus species*. Higher class number corresponds to lower quality of the stand. The values extracted from the reforestation guide are shown in Table 10 and

Table 11, where *Age* represents the stand age, *N* is the number of trees per hectare and *V (stem+branch) is the* tree stem wood and branch wood volume in m^3 per hectare.

Table 10. *Pinus sylvestris* yield table (low class (IV) and lowest class (V) quality production).

Class IV - for ML1			Class V - for ML2		
Age	N	V (stem+ branch)	Age	N	V (stem+ branch)
years	*trees/ha*	*m^3/ha*	*years*	*trees/ha*	*m^3/ha*
20	7,600	50	20	-	-
25	5,813	67	25	7,188	51
30	4,508	88	30	5,590	66
35	3,598	112	35	4,428	83
40	2,983	137	40	3,648	103
45	2,473	162	45	3,058	124
50	2,079	186	50	2,598	144

Class IV - for ML1			Class V - for ML2		
Age	**N**	**V (stem+ branch)**	**Age**	**N**	**V (stem+ branch)**
years	*trees/ha*	*m^3/ha*	*years*	*trees/ha*	*m^3/ha*
55	1,769	208	55	2,228	165
60	1,524	228	60	1,928	183
65	1,329	246	65	1,678	199
70	1,171	262	70	1,476	212
75	1,041	276	75	1,309	222
80	931	288	80	1,164	231
85	841	299	85	1,040	238
90	765	308	90	936	244
95	700	316	95	852	249
100	645	323	100	782	253
105	599	328	105	726	257
110	561	333	110	684	259
115	528	337	115	646	260
120	499	340	120	613	261

Table 11. *Quercus spp.* yield table (low class (III) and lowest class (IV) quality production).

Class III - for ML1			Class IV - for ML2		
Age	**N**	**V (stem+ branch)**	**Age**	**N**	**V (stem+ branch)**
	trees/ha	*m^3/ha*		*trees/ha*	*m^3/ha*
20	11,000	55	20	16,950	44
25	6,600	72	25	12,000	62
30	4,540	92	30	8,180	74
35	3,290	113	35	5,550	88
40	2,480	135	40	4,060	101
45	1,930	159	45	3,170	116
50	1,500	184	50	2,490	132
55	1,240	208	55	2,000	149
60	1,060	232	60	1,660	167
65	923	255	65	1,390	186
70	812	278	70	1,190	204
75	721	300	75	1,050	222
80	645	321	80	936	240

Class III - for ML1			Class IV - for ML2		
Age	N	V (stem+ branch)	Age	N	V (stem+ branch)
	trees/ha	*m³/ha*		*trees/ha*	*m³/ha*
85	579	341	85	832	258
90	529	361	90	754	275
95	485	381	95	688	292
100	448	400	100	628	309
105	413	419	105	580	326
110	383	436	110	538	342
115	356	453	115	500	357
120	333	469	120	468	371
125	292	500	125	409	409
130	259	530	130	360	437
135	233	558	135	320	463
140	212	585	140	285	489

2.2.3 Spain

The yield tables for the Spanish test sites were extracted from two sources:

The reforestation guide for Castilla y Leon (del Río et al., 2006) proposes reforestation and management plans for 3 coniferous species in Castilla y León (*Pinus pinaster, P. nigra* and *P. sylvestris*). The management plans consist of applying thinning to maintain the stand density within a defined threshold of observed density. Two site index values were selected for each species. Specifically, the most restrictive site index values were chosen (SI = 15 and SI = 12). Then, for each quality site, the yield was estimated for a management plan that considered silvicultural treatments (thinning). The tables extracted from the reforestation guide are shown in Table 12, Table 13, and Table 14, where *quality* is the stand quality, *Age* represents the stand age, H_o is the dominant stand height in meters, *N* is the number of trees per hectare, *Hm* is the stand mean height, *Dg* is the mean square diameter in cm, *G* is the basal area in m^2 per hectare and *V* is the tree wood volume in m^3 per hectare.

Table 12. *Pinus pinaster* yield table (lowest class (12) and second-lowest class quality production).

Species	Quality	Age	Before thinning					Thinning			After thinning			
			Ho	N	Dg	G	V	N	Dg	V	N	Dg	G	V
		years	*m*	*trees/ ha*	*cm*	*m²/ ha*	*m³/ ha*	*trees/ ha*	*cm*	*m³/ ha*	*trees/ ha*	*cm*	*m²/ ha*	*m³/ ha*
P. pinaster	12	40	10.4	1,500	13	21.1	92.8	575	12	29.4	925	14	14.6	63.4
P. pinaster	12	50	12	925	19	26.9	136	375	16.7	42.4	550	20.8	18.6	93.2
P. pinaster	12	65	13.6	550	27	31.2	178	150	24.2	40.1	400	27.8	24.3	138

Species	Quality	Age	Before thinning					Thinning			After thinning			
			Ho	N	Dg	G	V	N	Dg	V	N	Dg	G	V
		years	*m*	*trees/ ha*	*cm*	*m^2/ ha*	*m^3/ ha*	*trees/ ha*	*cm*	*m^3/ ha*	*trees/ ha*	*cm*	*m^2/ ha*	*m^3/ ha*
P. pinaster	12	80	14.6	400	33	33.1	202	-	-	-	-	-	-	-
P. pinaster	15	35	11.7	1500	14	24.2	119	575	12.9	37.8	925	15.2	16.7	81.6
P. pinaster	15	45	14.1	925	21	31.2	183	375	18.0	57.2	550	22.4	21.6	126
P. pinaster	15	60	16.5	550	29	36.1	246	200	26.0	73.8	350	30.4	25.5	172
P. pinaster	15	75	17.9	350	37	37.9	280	-	-	-	-	-	-	-

Table 13. *Pinus nigra* yield table (lowest class (12) and second-lowest class quality production).

Species	Quality	Age	Before thining					Thining			After thining			
			Ho	N	Dg	G	V	N	Dg	V	N	Dg	G	V
		years	*m*	*trees/ ha*	*cm*	*m^2/ ha*	*m^3/ ha*	*trees/ ha*	*cm*	*m^3/ ha*	*trees/ ha*	*cm*	*m^2/ ha*	*m^3/ ha*
P. nigra	12	45	10.8	1,500	17	33.3	161	500	15	42.8	1,000	18	24.5	118
P. nigra	12	60	14.3	1,000	22	37.9	234	350	19.1	62.3	650	23.3	27.8	171
P. nigra	12	75	17.2	650	27	36.2	263	225	22.6	66.3	425	28.5	27.2	197
P. nigra	12	85	18.9	425	30	29.8	234	-	-	-	-	-	-	-
P. nigra	15	40	12.2	1500	19	40.8	220	550	16.6	64.3	950	19.7	29	156
P. nigra	15	55	16.3	950	25	45.3	313	350	21.4	88	600	26.3	32.6	225
P. nigra	15	70	19.5	600	30	41.8	339	200	25.3	82.1	400	31.8	31.7	257
P. nigra	15	80	21.3	400	33	34.4	300	-	-	-	-	-	-	-

Table 14. *Pinus sylvestris* yield table (lowest class (12) and second-lowest class quality production).

Species	Quality	Age	Before thinning					Thinning			After thinning			
			Ho	N	Dg	G	V	N	Dg	V	N	Dg	G	V
		years	*m*	*trees/ ha*	*cm*	*m^2/ ha*	*m^3 /ha*	*trees/ ha*	*cm*	*m^3/ ha*	*trees/ ha*	*cm*	*m^2/ ha*	*m^3/ ha*
P. sylvestris	12	40	9.4	1,500	15	26.8	115	500	13.4	30.9	1,000	15.9	19.7	83.7
P. sylvestris	12	55	13.2	1,000	20	30.1	176	375	16.6	48.6	625	21.1	21.9	127
P. sylvestris	12	70	13.9	625	25	29.9	183	175	22.2	42.3	450	25.6	23.2	141
P. sylvestris	12	110	15.9	450	31	34.8	241	-	-	-	-	-	-	-
P. sylvestris	15	35	10.4	1,500	16	29.1	137	550	14.0	40.4	950	16.6	20.6	96.1
P. sylvestris	15	50	15	950	21	32.8	215	375	17.8	62.4	575	22.8	23.4	152
P. sylvestris	15	65	16.9	575	27	32.2	235	175	24.0	59.1	400	27.8	24.3	176
P. sylvestris	15	110	19.9	400	34	37.2	315	-	-	-	-	-	-	-

Montero's yield table for *Pinus halepensis* (Montero et al., 2001). The yield table is built using information from 72 forest plots distributed within the natural distribution of Pinus halepensis and representing a wide range of site qualities. The plots were distributed throughout eastern and central easter Span, in the provinces of Albacete, Castellón, Jaén, Murcia, Teruel, Valencia, and Zaragoza. The document also provides a classification of the yield using as quality indicator Richard's site index (Richards, 1959). In addition, several silvicultural regimes are proposed which determine the final yield output. The SI indexes selected for *Pinus halepensis* were 11 and 14. Table 15 shows the yield table of *Pinus halepensis*.

Table 15. *Pinus halepensis* yield table (lowest class (12) and second-lowest class quality production).

Species	Quality	Age	Before thining					thining				After thining			
			Ho	N	Dg	G	V	N	Dg	G	V	N	Dg	G	V
		years	m	trees/ha	cm	m^2/ha	m^3/ha	trees/ha	cm	m^2/ha	m^3/ha	trees/ha	cm	m^2/ha	m^3/ha
P. halepensis	11	20	4.5	2,103	5.9	5.7	12.9	65	2.5	0	0.1	2,038	6	5.7	13
P. halepensis	11	30	6.2	2,038	8	10.1	30.2	86	3	0	0.3	1,952	8.1	10.1	30.1
P. halepensis	11	40	7.5	1,952	9.8	14.6	51.2	647	4	0.8	3.6	1,305	11.6	13.8	47.1
P. halepensis	11	50	8.7	1,305	13	17.1	65.8	72	6.1	0.2	4.5	1,233	13.2	16.9	64.8
P. halepensis	11	60	9.6	1,233	14	19.9	82.7	227	7.7	1.1	9.3	1,005	15.4	18.8	77.5
P. halepensis	11	70	10.4	1,005	16	21.1	92.5	143	9	0.9	13.7	862	17.3	20.2	87.8
P. halepensis	11	80	11	862	18	21.9	100	96	10.2	0.8	17.6	766	18.8	21.2	96.1
P. halepensis	11	90	11.5	766	19	22.6	107	67	11.1	0.6	21	699	20	21.9	102.9
P. halepensis	11	100	11.9	699	21	23	112	49	11.8	0.5	23.8	650	21	22.5	108.5
P. halepensis	11	110	12.3	650	21	23.4	116	37	12.4	0.4	26.2	613	21.8	23	113
P. halepensis	11	120	12.6	613	22	23.7	119	–	–	–	–	–	–	–	–
P. halepensis	14	20	5.7	1,586	8.5	9	24.7	105	3	0.1	0.2	1,481	8.8	9.1	24.7
P. halepensis	14	30	7.8	1,481	11	15	53.3	139	4.7	0.2	1.2	1,342	11.8	14.7	52.1
P. halepensis	14	40	9.6	1,342	14	20.3	85	336	7.6	1.5	8.2	1,006	15.4	18.8	77.4
P. halepensis	14	50	11	1,006	17	23.2	107	29	9.9	0.2	9.3	977	17.3	23	105.9
P. halepensis	14	60	12.2	977	19	26.8	135	180	11.7	1.9	19.7	797	19.9	24.9	123.6
P. halepensis	14	70	13.2	797	21	27.9	147	113	13.3	1.6	28.7	684	22.1	26.3	137.9
P. halepensis	14	80	14	684	23	28.6	157	76	14.7	1.3	36.3	608	23.9	27.3	149.5
P. halepensis	14	90	14.7	608	25	29.1	166	53	15.8	1	42.6	554	25.4	28.1	158.9
P. halepensis	14	100	15.2	554	26	29.5	172	39	16.7	0.9	47.9	515	26.6	28.6	166.5
P. halepensis	14	110	15.7	515	27	29.8	177	29	17.4	0.7	52.4	486	27.6	29.1	172.8
P. halepensis	14	120	16	486	28	30	182	–	–	–	–	–	–	–	234

2.2.4 Greece

The growth simulation was calculated for the two selected species for the Greek marginal lands: *Pinus halepensis* and *Quercus sp.* Given the lack of information on *Pinus halepensis* yield estimations for Greece, Spanish yield tables were used (G. Montero et al., 2000). Despite being from a different geographical area, both ecological distributions preserve similar environmental characteristics. Therefore, the yield values proposed by Montero were considered suitable for the Greek pilot sites. For the *Quercus sp.* Kossenakis yield tables for coppice stands of *Quercus frainetto* Ten., were used (Kossenakis, 1939). Site indexes selected for *Pinus halepensis* were equivalent to 14 for marginal lands of type 1, and production class Vb was selected for *Quercus sp.* On the other hand, the yield values for the site index equal to 11 were used for the marginal lands type 2 for *Pinus halepensis*, while the yield class Va was chosen for the lowest productivity type of the marginal lands for *Quercus sp*. The yield tables selected were presented in Table 16 and Table 17, where *SI* is the stand quality, *year* represent the stand age, *N* is the number of trees per hectare, *Hm* is the stand mean height in meters, *G* basal area m^2 per hectare, *DBH* is the diameter at breast height in cm*, Vol+bark* is the stand tree wood and bark volume in m^3 per hectare, *Vol is the* stand tree wood volume in m^3 per hectare and *Dry weight* is the dry biomass of the trunk volume.

Table 16. Quercus species yield table. Class quality Va (second lowest production).

SI	Age	N	Hm	G	DBH	Vol+ bark	Vol	Dry weight
	year	trees/ ha	m	m^2/ ha	cm	m^3/ ha	m^3/ ha	m^3/ ha
Va	10	9,100	3.2	6.4	3	16	10.46	11,840
Va	12	8,820	3.7	6.88	3.1	19.6	12.84	14,504
Va	14	8,540	4.2	7.35	3.3	23.4	15.42	17,316
Va	15	8,400	4.4	7.72	3.4	25.6	16.92	18,944
Va	16	8,262	4.6	8.1	3.5	27.8	18.42	20,572
Va	18	7,980	5	8.78	3.7	32.4	21.59	23,976
Va	20	7,700	5.4	9.38	3.9	36.6	24.53	27,084
Va	22	7,380	5.7	9.9	4.1	40.6	27.39	30,044
Va	24	7,060	6	10.3	4.3	44.2	30.04	32,708
Va	25	6,900	6.2	10.4	4.4	45.8	31.3	33,892
Va	26	6,700	6.3	10.6	4.5	47.35	32.48	35,039
Va	28	6,300	6.6	10.8	4.7	50.4	34.78	37,296
Va	30	5,900	6.9	11	4.9	53.2	36.96	39,368
Va	32	5,420	7.1	11.2	5.1	55.8	39	41,292
Va	34	4,940	7.4	11.3	5.4	58	40.87	42,920
Va	35	4,700	7.5	11.4	5.5	59.1	41.76	43,734
Va	36	4,620	7.6	11.5	5.6	60.1	42.58	44,474
Va	38	4,460	7.8	11.5	5.7	62.1	44.11	45,954
Va	40	4,300	8	11.6	5.8	63.9	45.51	47,286
Va	42	4,300	8.2	16.2	5.9	65.7	46.82	48,618
Va	44	4,300	8.4	16.3	5.9	67	47.85	49,580
Va	45	4,300	8.5	16.4	5.9	67.7	48.35	50,098

Table 17. Quercus species yield table. Class quality Vb (lowest production).

SI	Age	N	Hm	G	DBH	Vol+ bark	Vol	Dry weight
	year	trees/ ha	m	m^2/ ha	cm	m^3/ ha	m^3/ ha	m^3/ ha
Vb	10	9,300	2.8	5.3	2.7	12.1	7.69	8,954
Vb	12	9,020	3.3	5.55	2.8	15	9.56	11,100
Vb	14	8,740	3.7	6.27	3	18.3	11.75	13,542
Vb	15	8,600	3.9	6.54	3.1	20	12.87	14,800
Vb	16	8,460	4.1	6.79	3.2	21.7	14	16,058
Vb	18	8,180	4.5	7.42	3.4	25.4	16.46	18,796
Vb	20	7,900	4.8	7.9	3.6	18.8	18.75	13,912
Vb	22	7,580	5.1	8.31	3.7	32	20.88	23,680
Vb	24	7,260	5.4	8.7	3.9	35	22.95	25,900
Vb	25	7,100	5.6	8.8	4	36.4	23.92	26,936
Vb	26	6,900	5.7	8.92	4.1	37.6	24.83	27,824
Vb	28	6,500	6	9.1	4.2	39.9	26.57	29,526
Vb	30	6,100	6.2	9.3	4.4	42.1	28.2	31,154
Vb	32	5,620	6.5	9.36	4.6	44	29.76	32,560
Vb	34	5,140	6.7	9.4	4.9	45.6	31.28	33,744
Vb	35	4,900	6.8	9.43	5	46.4	31.97	34,336
Vb	36	4,820	6.9	9.47	5.1	47.3	32.6	35,002
Vb	38	4,620	7.2	9.54	5.2	48.8	33.82	36,112
Vb	40	4,500	7.4	9.6	5.2	50.5	35	37,370
Vb	42	4,500	7.5	9.66	5.3	52	36.14	38,480
Vb	44	4,500	7.7	9.72	5.3	53.5	37.19	39,590
Vb	45	4,500	7.8	9.75	5.3	54.2	37.67	40,108

2.3 Biomass and Carbon estimation

For biomass estimation two sources for estimating biomass were consulted depending on data availability:

- Biomass functions are based on allometric equations which provide a relationship between the stem volume and different tree parts (leaves, branches, etc.). To establish those relationships biomass functions are built on variables extracted from forest inventory data. Biomass functions can also estimate directly the total biomass of the tree, i.e. generalized biomass equations. However, for our purpose it was more interesting to consider additive components biomass functions where the total biomass of the tree can be obtained by the aggregation of the individual parts of the component (Neumann et al., 2016).
- Biomass Conversion and Expansion Factor (BCEF). BECF are ratios that relate the volume between the above-ground biomass (ABG) with the belowground biomass

(BGB) and the stem and are based on generalized allometric relationships for each species or group of species. Not only BCEF can refer to relationships between ABG and BGB, but also between stem and other parts of the tree such as leaves, branches, roots, etc. BCEF could be found for the main forestry species in (Montero et al., 2005). Alternatively, general values were obtained from the IPCC 2019 Guidelines Chapter 4 (Aalde et al., 2006).

2.3.1 Germany

For the German pilot sites, the biomass was estimated using several biomass equations. For above-ground biomass, (Vonderach et al., 2018) additive biomass functions for German forest species were used. The AGB equations were parametrized 8 species, for all of them regressions coefficients were adjusted for the different components of the aerial part and several equations were set. The components were described in

Table 18.

Table 18. Components of the German forest species biomass equations.

Component	Description
stw	Stump wood
stb	Bark of stump wood
stwb	Stump wood incl. bark
cww	Coarse wood (≥ 7 cm in diameter)
cwb	Bark of coarse wood (≥ 7 cm in diameter)
cwwb	Coarse wood (≥ 7 cm in diameter) incl. bark
sw	Small wood (< 7 cm in diameter) incl. bark
nd	Needles
agb	Total above-ground biomass

Next, the ABG component equations for the *Pinus sylvestris* and *Picea abies* are shown in Table 19.

Table 19. AGB Components biomass equations for the *Pinus sylvestris* and *Pices abies*.

Species	Type	Comp.	Equation
Pinus sylvestris	Simple	stw	$0.0624 \cdot dbh^{1.9322} \cdot sth^{1.0414}$
		stb	$0.0077 \cdot dbh^{1.8127} \cdot sth^{0.8732}$
		stwb	stw + stb
		cww	$0.0173 \cdot dbh^{2.0072} \cdot h^{0.914}$

Species	Type	Comp.	Equation
		cwb	$0.0055 \cdot dbh^{2.0108} \cdot h^{0.5374}$
		cwwb	cww + cwb
		sw	$0.1316 \cdot dbh^{2.444} \cdot h^{-0.949}$
		nd	$0.1484 \cdot dbh^{2.332} \cdot h^{-1.2026}$
		agb	Sum of all components
Picea abies	Simple	stw	$0.022 \cdot dbh^{2.1212} \cdot sth^{0.6056}$
		stb	$-0.0128 + 0.0067 \cdot dbh^{1.7268} \cdot sth^{0.5947}$
		stwb	stw + stb
		cww	$0.0142 \cdot dbh^{1.7414} \cdot h^{1.2401}$
		cwb	$0.0038 \cdot dbh^{1.6076} \cdot h^{1.0528}$
		cwwb	cww + cwb
		sw	$1.8472 + 0.0243 \cdot dbh^{2.9671} \cdot h^{-0.8183}$
		nd	$-1.6847 + 0.285 \cdot dbh^{2.1173} \cdot h^{-0.8334}$
		agb	Sum of all components

Out of all the equations for the different above-ground biomass components proposed in the document, only the equations which had as parameters the mean height and the mean diameter at breast height were selected. Therefore, the stump wood, the stump wood including bark, and the bark of stamp wood equations were excluded because the stump height was required as an input parameter. The rest of the equations were used for the estimation of the above-ground biomass. Although the exclusion of the stump biomass diminishes the estimations on the total above-ground biomass, we consider that this fraction can be neglected for the total above-ground biomass estimation without creating a strong bias in the final output.

For the estimation of the below-ground biomass, generalized biomass equations were used.

Equation 1. $$BGB = b_0 * DBH^{b_1}$$

The equations proposed by (Bolte A et al., 2004) used in the German National Greenhouse Inventory (Röhling et al., 2016) were chosen to estimate the below-ground biomass for the Picea abies for the region of Solling, whereas for the Pinus sylvestris we used the equation in (Röhling et al., 2019) because more trees were accounted for the parameterization than in the equation used in the National greenhouse inventory of Germany 2012. Next,

Table 20 containing the BGB equations and coefficients adjusted for each species is presented:

Table 20. BGB equations and coefficients adjusted for each species for the *Pinus sylvestris* and *Pices abies*.

BGB						
Tree species	**b0**	**Parameter**	**b1**	**RMSE (%)**	**Region**	**Source**
Picea abies	0.00372	DBH (cm)	2.792465	3.6	Solling	(Bolte A et al., 2004)
Pinus sylvestris	0.010617	DBH (cm)	2.593122	13.7	-	(Röhling et al., 2016)

2.3.2 Poland

Total biomass of potential forest in Polish test site was calculated using BECF and values of Basic Specific Density (Table 25). Additionally, ABG and BGB were calculated using information about tree components percentage (stem, branch, foliage) in total biomass, available in scientific papers (Table 21). In case of the *Pinus Sylvestris* values were obtained from research performed in Poland (Chmura et al., 2013). For the *Quercus species* no research from Poland was available, and values from Czechia for *Quercus robur* were used (Krejza et al., 2017). Carbon content was estimated as 50% of dry tree biomass.

Table 21. Proportions between the above-ground and below-ground biomass used for Polish test site.

	AG Biomass			Tree	
Species	***Stem (%)***	***Branch (%)***	***Foliage (%)***	***AG Biomass (%)***	***BG Biomass (%)***
Pinus pinaster	57.0	17.2	9.6	83.7	16.3
Quercus spp.	63.0	18.0	1.0	82.0	18.0

2.3.3 Spain

Biomass was estimated in Spain using Montero's 2005 (Gregorio Montero et al., 2005) allometric relationships for the Spanish forest's species. First, biomass for the stem volume was estimated using specific wood density for each species (Rodríguez et al., 2006) presented in Table 25, then Montero's allometric relationships or BECF were applied to the stem biomass to obtain the biomass for other parts of the tree.

The proportions or BCEF between the above-ground and below-ground biomass for the Spanish forest species are presented in Table 22. It is important to note that these proportions are generalized for the species and can differ for different growth stages of the tree.

Table 22. Proportions between the above-ground and below-ground biomass for *Pinus pinaster, P.nigra, P.sylvestris, and P. halepensis* (Montero et al., 2005).

	AG Biomass				Tree	
Species	***branch >7cm (%)***	***branch 2-7cm (%)***	***branch < 2cm (%)***	***Stem (%)***	***AG Biomass (%)***	***BG Biomass (%)***
Pinus pinaster	1.2	5.3	14.0	79.5	77.9	22.1
P. nigra	6.7	9.9	19.8	63.6	80.4	19.6
P. sylvestris	3.2	9.0	9.4	71.3	78.6	21.4
P. halepensis	12.8	11.0	27.8	48.4	76.4	23.6

With the biomass, the values from the different parts of the tree, the carbon content of the biomass is calculated applying the species carbon fraction ratio for dry biomass. This ratio was extracted from Montero 2005 (Table 23).

Table 23. Species carbon fraction ratio for dry biomass for *Pinus pinaster, P.nigra, P.sylvestris, and P. halepensis* (Montero et al., 2005).

Species	C% in dry wood
Pinus pinaster	51.1
P. nigra	50.9
P. sylvestris	50.9
P. halepensis	49.9

2.3.4 Greece

The biomass estimation on Greece was calculated using Biomass expansion factors that were applied to the biomass calculated in the Yield tables of Kossenakis. Kossenakis obtained the stem biomass values by multiplying the volume by a wood density parameter previously calculated to produce the yield table. Here, the estimation of wood density for the *Quercus frainetto Ten.*, in Greece is 740 kg/dm^3. Next, the biomass for the above-ground biomass pool was estimated using a generalized relationship for above-ground parameters for oak (*Quercus frainetto, Quercus cerris* L., and *Quercus petraea* Matt.) coppice forests for Northern Turkey (Thrace)(Ozdemir et al., 2019). The selection of these biomass relationships is based on several factors:

- the date of the study. Other biomass coppice studies are conducted in less relatable areas and are not as recent (Albert et al., 2014). Other extensive review studies compiling existing biomass equation equations were checked, however, no information was offered for *Quercus frainetton* (Zianis et al., 2005)
- the application of oak coppice forest biomass equations to oak coppice forest Kossenaki's yield table (Kossenakis, 1939).In this case, we deem that the forest

structure is significant and therefore biomass equation should reflect that structure, despite differing the study area.

The above-ground biomass relationships for *Quercus frainetto* forest are reflected in Table 24.

The ratio between the above-ground proportion between the above-ground biomass and below-ground biomass in *Quercus frainetto* forest could not be found for this study area or any relatable one. Therefore, as the above-ground/below-ground biomass ratio, it was used the one proposed in the IPCC guidelines chapter 4 (Aalde et al., 2006), for the subtropical dry forest with above-ground biomass values superior to 20 tones by a hectare (28%).

Table 24. ABG relationships for *Quercus frainetto* forest in Northern Turkey.

Species	Foliage (%)	Branch (%)	Bark (%)	Stem (%)	Stem+bark (%)
Quercus frainetto	11.87	18	13.85	56.28	70.13

2.4 Wood density values

Wood density values were obtained for each species where the biomass estimation methodology involved the conversion from a stem volume to stem biomass. For this conversion, it is necessary to know the normal density of the dry wood for a given species (Equation 3).The pilot sites where volume to biomass conversion was applied were in Staszów (Poland), Thessaloniki (Greece), Komotini (Greece), Nogueruelas (Spain), Espadán (Spain), Soria (Spain). For Germany, the biomass was estimated using accumulative biomass equations, therefore German forest species were excluded (*Picea abies* and *Pinus sylvestris*).

Table 25. Wood density values for the forest species selected for Poland, Spain, and Greece.

Country	Species	Normal density/ Basic Specific Gravity (kg/dm^3)	Source
Spain	*Pinus pinaster*	0.52	(Rodríguez et al., 2006)
Spain	*P. nigra*	0.62	(Rodríguez et al., 2006)
Spain	*P. sylvestris*	0.56	(Rodríguez et al., 2006)
Poland	*P. sylvestris*	0.42	Spike
Spain & Greece	*P. halepensis*	0.61	(Rodríguez et al., 2006)
Greece	*Quercus frainetto*	0.74	(Kossenakis, 1939b)
Poland	*Quercus spp.*	0.56	Spike

3 MARGINAL LAND AREA FOR STUDY SITES

To estimate the area to be reforested, it is necessary to know the marginal areas present in each of the eight pilot sites: Staszów (Poland), Thessaloniki (Greece), Komotini (Greece), Welzow (Germany), Nochten (Germany), Nogueruelas (Spain), Espadan (Spain) and Soria (Spain). For this purpose, we worked with the surfaces calculated in task 2.3 "Methodology development" and the results described in deliverable 2.3 "Report on Methodology development". In task 2.3 the methodology for the identification of marginal lands and their corresponding degree of marginality ("Marginal lands with high plantation suitability", "Marginal lands with low plantation suitability", "Potentially unsuitable lands") was elaborated for Europe. As a result of this task, a European layer of marginal lands was obtained and the degree of marginality was calculated following three methodological approaches (Table 26):

a) The first is to calculate the maximum and minimum value obtained in the MLs layer and divide the difference by three. This will obtain three ranges of equal magnitude.

b) The second methodological approach is to calculate the 25th and 75th percentiles of the values obtained in the MLs layer. This approach would penalize the “Marginal lands with high plantation suitability” and the "Potentially unsuitable lands" and increasing the number of pixels belonging to the middle layer "Marginal lands with low plantation suitability".

c) The third one is to calculate the 33rd and 66th percentile of the values obtained in the layer MLs. In this case, the total number of pixels is divided equally into three categories. But with the difference concerning the a) method that in this case the thresholds are established with the maximum number of pixels and not with the maximum and minimum values.

Table 26. Methods to subdivide by type of marginality (“Marginal lands with high plantation suitability”, “Marginal lands with low plantation suitability”, and “Potentially unsuitable lands”). Source: Deliverable 2.3 *MAIL* project.

Method		a)		b)		c)	
		Max. -	Min.	P25 -	P75	P33 -	p66
Value		6.862	0.120	1.390	2.890	1.579	2.516
		Thresholds					
1	***Marginal lands with high plantation suitability***	6.862	4.615	6.862	2.890	6.862	2.516
2	***Marginal lands with low plantation suitability***	4.615	2.367	2.890	1.390	2.516	1.579
3	***Potentially unsuitable lands***	2.367	0.120	1.390	0.120	1.579	0.120

Besides, in chapter 12 of deliverable 2.3, the areas under marginal lands classification were analyzed for each method implemented on the pilot sites as shown in Figure 1.

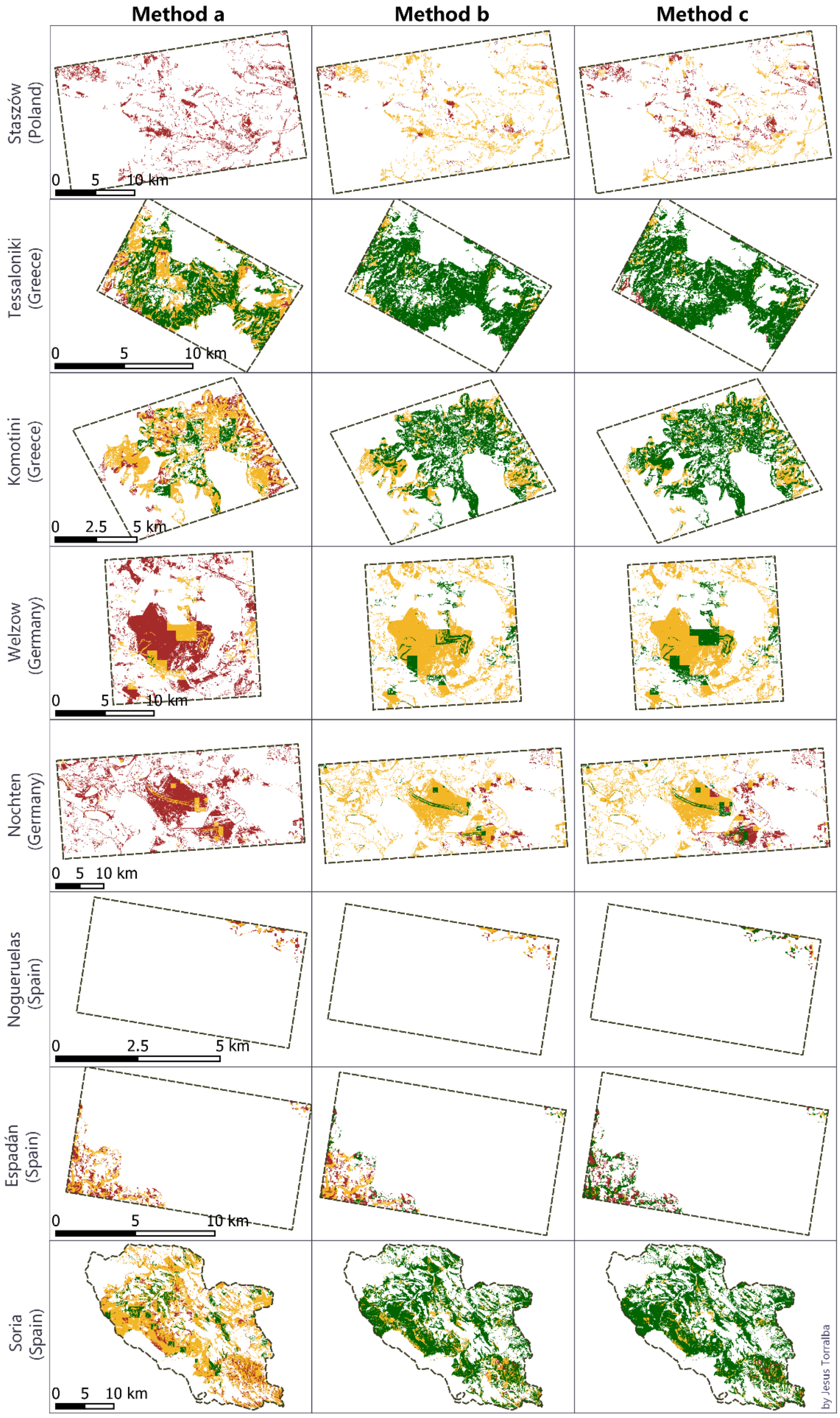

Figure 1. The final layer of MLs classified with 3 methods into 3 categories "Marginal lands with high plantation suitability" (green), "Marginal lands with low plantation suitability" (gold), and "Potentially unsuitable lands" (dark red) in the pilot sites. Source: Deliverable 2.3 *MAIL* project.

Table 27 shows the area occupied by each marginality category "Marginal lands with high plantation suitability", "Marginal lands with low plantation suitability", "Potentially unsuitable lands" for each method on each pilot site. Also, the percentage that marginal lands represent over the total area of each pilot site.

Table 27. Hectares and percentage of total area for each of the ML categories according to marginality ("Marginal Lands with high plantation suitability", "Marginal Lands with low plantation suitability", and "Potentially unsuitable lands") for each pilot site and method. Source: Deliverable 2.3 *MAIL* project.

		Poland (Staszów)		Greece (Tessaloniki)		Greece (Komotini)		Germany (Welzow)		Germany (Nochten)		Spain (Nogueruelas)		Spain (Espadán)		Spain (Soria)	
Method	**Type**	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
A	***MLs with high plantation suitability***	0.0	0.0	2,596.9	26.9	568.9	7.1	27.1	0.1	6.6	0.0	0.0	0.0	0.0	0.0	3,611.5	6.3
	MLs with low plantation suitability	19.6	0.0	1,887.3	19.5	1,809.6	22.6	1,554.8	7.0	2,023.3	1.9	12.7	0.5	341.8	3.0	19,194.2	33.3
	Potentially unsuitable lands	4,076.4	8.5	147.3	1.5	435.0	5.4	4,951.2	22.3	19,090.6	18.3	14.6	0.6	282.0	2.4	2,913.7	5.0
	Total MLs	4,096.0	8.5	4,631.5	47.9	2,813.5	35.2	6,533.0	29.4	21,120.5	20.3	27.3	1.2	623.9	5.4	25,719.3	44.6
B	***MLs with high plantation suitability***	17.8	0.0	4,377.4	45.3	2,024.8	25.3	1,095.4	4.9	1,255.5	1.2	0.3	0.0	103.0	0.9	20,367.3	35.3
	MLs with low plantation suitability	3,487.6	7.3	243.6	2.5	788.7	9.9	5,437.6	24.5	17,891.5	17.2	21.0	0.9	272.1	2.4	5,082.2	8.8
	Potentially unsuitable lands	590.6	1.2	10.5	0.1	0.0	0.0	0.0	0.0	1,973.5	1.9	6.0	0.3	248.7	2.2	269.9	0.5
	Total MLs	4,096.0	8.5	4,631.5	47.9	2,813.5	35.2	6,533.0	29.4	21,120.5	20.3	27.3	1.2	623.9	5.4	25,719.3	44.6
C	***MLs with high plantation suitability***	18.9	0.0	4,391.9	45.4	2,241.5	28.0	1,581.1	7.1	1,933.4	1.9	12.7	0.5	341.2	3.0	22,587.9	39.1
	MLs with low plantation suitability	1,682.5	3.5	161.5	1.7	572.0	7.2	4,952.0	22.3	14,043.5	13.5	8.3	0.4	33.7	0.3	2,751.0	4.8
	Potentially unsuitable lands	2,394.6	5.0	78.1	0.8	0.0	0.0	0.0	0.0	5,143.6	4.9	6.4	0.3	249.0	2.2	380.5	0.7
	Total MLs	4,096.0	8.5	4,631.5	47.9	2,813.5	35.2	6,533.0	29.4	21,120.5	20.3	27.3	1.2	623.9	5.4	25,719.3	44.6

4 METHODOLOGY AND CARBON SEQUESTRATION CAPACITY ANALYSIS

4.1 Current biomass stock information integration

At this point, the evaluation of the current biomass stock on the pilot site's MLs is assessed. The goal is to study how current biomass stock is distributed within the marginality classes using open-source ABG biomass products (like ESA or NASA). According to the definition of MLs for the ***MAIL*** project and the proposed methodology for their identification, it is expected that the areas defined as MLs are devoid of vegetation and this assumption about the current state of marginal lands is the condition that has been taken as a reference to develop this methodology. In the case of pre-existing vegetation in the areas defined as marginal, it would be necessary to consider other reforestation methodologies that take into account the existing vegetation. The woody biomass in MLs was assumed as 0.

4.2 Methodology

To carry out the carbon sequestration capacity analysis in marginal lands a methodology is presented according to the different information available described in chapter 2 for every test site. The methodology follows the steps of an afforestation plan. However, it is not the goal of defining an afforestation plan for the pilot sites as many ancillary variables should be added that are currently out of the scope, such as pre-preparation of the terrain, available machinery, access to the areas, definition, and creation of forest roads, etc. Therefore, the main goal of the methodology is to forecast how certain planted species would evolve in the marginal lands.

Figure 2 presents an overview of the methodology which firstly addresses a description of the pilot site vegetation. An identification of all the main vegetation formations and species is required to decide what species are most suitable for the marginal lands. The species selected will be the most represented ones in the area. However, species with high nutrient or hydric requirements will be discarded as marginal lands are characterized for their poor soil conditions. Additionally, the plantations will be composed of two species to enhance the diversity of the marginal lands and make the future forest more resilient to disturbances such as pests, droughts, extreme climatic events.

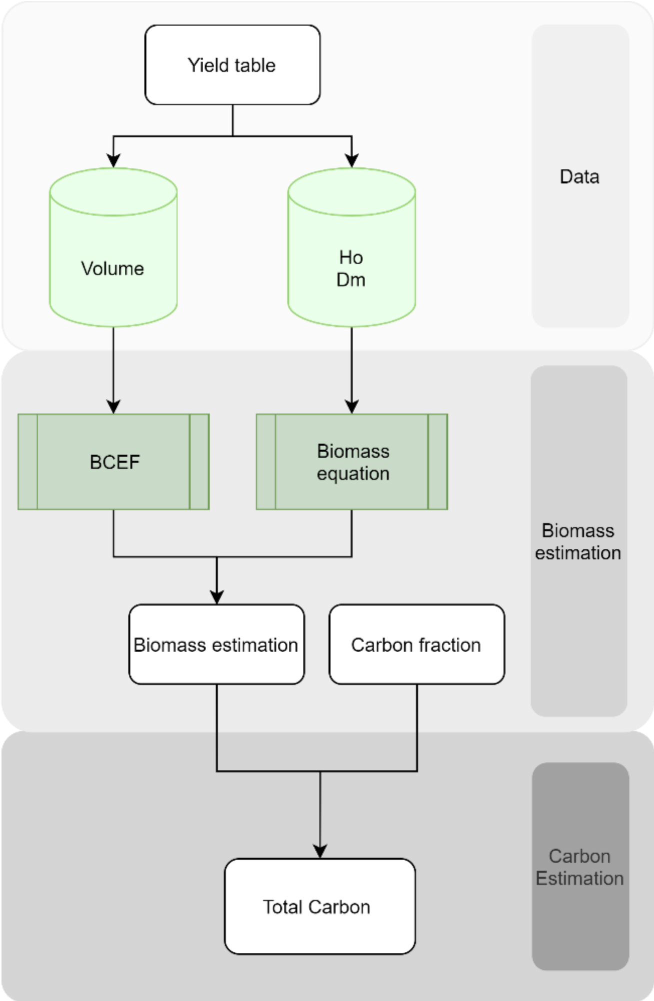

Figure 2. Methodology workflow.

After the definition of the species that will be planted in each test sit, the growth of the newly implanted forest must be forecasted for every species. This prediction is based on yield tables or growth models. Unfortunately, the option of using growth model inventory is constrained by inventory data unavailability. This limitation arises from the definition of ML created in task 2.1. which states that MLs do not present arboreal vegetation, where there is no forest inventory data. At this point, the methodology assumes that the forest inventory data used for the MLs will correspond with low site index areas, except those areas where marginality is not originated by environmental constraints, but social. Therefore, forest growth in marginal lands will be forecasted with yield tables and it is represented as the commercial wood volume for a given class age. To better reflect the environmental condition of the marginal lands, the two lowest site indexes of the yield tables for each species will be selected, corresponding to the lowest site index to the marginal lands classified as type 2 and the second the lowest site index to the ML type 1. Once the growth is forecasted the biomass is estimated in two components of the tree: the aerial part (branches, stem, and leaves) corresponding to the above-ground biomass (AGB) and the radicular tree components corresponding to the below-ground biomass (BGB). From here on, the methodology splits into two branches according to the data availability for the pilot sites and species:

On one hand, biomass equations specific for the selected species of the module were evaluated. The dasometric[3] stand variables from the yield tables were used as input for the biomass equations. Therefore, *dbh* and *height*-dependent allometric biomass equations were selected for the methodology, as more specific metrics such as crown diameter or branch diameter were not provided by the growth models.

On the other hand, if no biomass equations were found for the target species or, the input parameters were not included in the inventory or yield table data, the biomass equations were replaced by a Biomass Conversion and Expansion Factor (BCEF). Here we use the BCEF to relate stem dry biomass and the other parts of the tree (branches, leaves, ABG, and BGB) (equation 3, 4, Table 28) or to the whole tree biomass (equation 5, Table 28). To calculate the stem dry biomass, it is necessary to convert the stem volume (yield table's output) and multiply it by the specific gravity of the wood or normal density of the wood (equation 2, Table 28).

As a result of both aforementioned methods, a biomass estimation for the individual tree will be obtained for above ground and below-ground biomass. Next, the carbon is calculated by applying a carbon fraction for a given species and test site to biomass estimation for the different tree components (equation 8, Table 28). If no carbon fraction is specified, then the general carbon content in dry biomass suggested by the IPCC guidelines (50%) was used (Aalde et al., 2006). Finally, the carbon per tree values was extrapolated to the hectare using the density parameter from the yield tables. The whole methodology for carbon estimation using BCEF is simplified in equation 11 of the table of equations, where the calculation is optimized to avoid unnecessary steps. All the equations of the methodology can be consulted in Table 28.

For every pilot site, the carbon estimation for each type of ML (type 1: ML1 and type 2: ML2) was calculated by hectare and for the total area. A value of carbon was reported considering the mixture between the two species selected. The degree of mixture ranges in steps of 10% from 0% (purity of species 1) to 100% (purity of species 2) where 50% is the equal combination of both species.

[3] Relative to the forest

Table 28. Equations for carbon estimation based on yield table data and BECF.

Nº	Equation	Units
Equation 2	$V_{tree} = \frac{V_{plot}}{N} * 1000$	▪ V_{tree} (dm^3/ha) ▪ N (trees/ha) ▪ V_{plot} (m^3/ha)
Equation 3	$ABG_{Stem} = V_{tree} * D$	▪ Density (D) (kg/dm^3) ▪ AGB_{Strem} (kg/tree)
Equation 4	$ABG_{branches} = ABG_{stem} * BECF_{branches}$	▪ $AGB_{Branches}$ (kg/tree) ▪ $BECF_{branches}$ (%)
Equation 5	$ABG_{tree} = \frac{ABG_{stem}}{BECF_{stem}}$	▪ AGB_{tree} (kg/tree) ▪ $BECF_{stem}$ (%) *Proportion of the stem over the ABG*
Equation 6	$Total\ Biomass_{tree} = \frac{ABG_{tree}}{BECF_{ABG}}$	▪ Total $Biomass_{tree}$ (kg/tree) ▪ $BECF_{ABG}$ (%): *Proportion of the ABG over the whole tree*
Equation 7	$BGB_{tree} = Total\ Biomass_{tree} - ABG_{tree}$	▪ BGB_{tree} (kg/tree)
Equation 8	$Total\ Biomass_{ha} = Total\ Biomass_{tree} * N$	▪ Total $Biomass_{ha}$ (kg/tree)
Equation 9	$Carbon = Biomass * CF$	▪ Biomass (kg) ▪ Carbon Fraction (CF) (%)
Equation 10	$Total\ Biomass_{ha} = \frac{\left(\frac{V_{plot}}{N} * 1000\right) * D}{BECF_{stem}} * BECF_{ABG} * N$	
Equation 11	$Total\ Carbon_{ha} = \frac{\left(\frac{V_{plot}}{N} * 1000\right) * D}{BECF_{stem}} * BECF_{ABG} * N * CF$	
Equation 12	$Total\ Carbon_{ha} = 1000 * V_{plot} * D * BECF_{ratio} * CF$	
Equation 13	$BECF_{ratio} = \frac{BECF_{ABG}}{BECF_{stem}}$	

5. RESULTS

Biomass and carbon sequestration capacity were estimated for 8 test sites in 4 countries. The obtained values describe carbon which may be stored within one hectare of marginal lands. To provide biodiversity, we proposed various scenarios of how to mix 2 species in different proportions. It can be used as a reference table for future afforestation plans. Thanks to these tables we can see how much carbon can be stored if a specific species mixture is applied. Additionally, as the way of estimating the ML area differs depending on the methodology selected (Chapter 3 “Marginal Land Area for study sites”), values for each method were calculated. For the results, we showed the carbon estimations corresponding to methodology C. Results for methodology A and B are in “Annex III: Carbon estimation for the pilot site: Results”.

5.1 Germany

The area within the federal state of Saxony was selected as a test site in Germany. The aforementioned state includes lowland areas of low productivity while post-mining areas are also a distinctive land use in the region. More specifically, Nochten and Welzow sites located in the northern part of the federal state of Saxony (Figure 3), have been selected as representative pilot sites which include large post-mining areas that could be defined as Marginal Lands.

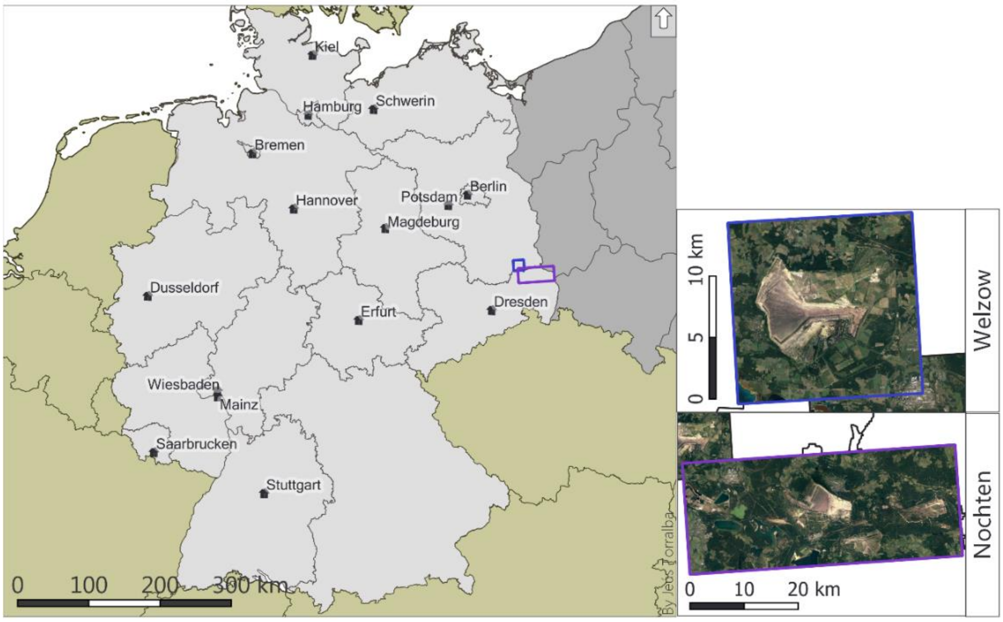

Figure 3. Germany (left) and the pilot sites of “Welzow” (outlined with blue) and “Welzow” (outlined with purple).

5.1.1 Species selection

In Germany, the pilot site is in the landers of Sachsen and Brandenburg. The National Forest Inventory was consulted to select the main forest species distributed in the study area.

Table 29. Area distribution for the main species in the German landers of Brandenburg + Berlin and Sachsen.

Land	Brandenburg + Berlin	Sachsen	Germany (all Länder)
Measure	*%*	*%*	*%*
Oak	6.59	8.59	10.38
Beech	3.30	4.23	15.43
Other deciduous trees with a long life expectancy	3.35	4.09	7.07
Other deciduous trees with a short life expectancy	11.28	14.59	10.54
All deciduous trees	24.52	31.50	43.42
Spruce	1.80	34.38	25.38
Fir	0.00	0.15	1.68
Douglas fir	0.97	0.20	2.00
Pine	70.14	28.20	22.31
Larch	1.17	3.42	2.82
All coniferous trees	74.07	66.35	54.19
Gap	1.18	1.67	2.02
Temporarily unstocked area	0.22	0.48	0.38
All tree species	100	100	100

As shown in Table 29, the most represented species are the pine (*Pinus sylvestris*) dominant in the Brandenburg region, and the spruce (*Picea abies*) in Sachsen. Given that the pilot site is allocated in both regions, it is proposed to select both species for the reforestation modules. Unfortunately, no disaggregated data in smaller administrative units have been found for the German forest inventory.

5.1.2 Biomass and carbon estimation by species

The results for the biomass estimations for the selected German forest species (*Pinus sylvestris and Picea abies*) applying biomass equations in section 2.3.1 are presented in Table 30, Table 31, Table 32, Table 33, Table 34, Table 35, Table 36 and Table 37.

Table 30. Biomass and Carbon estimates for *Pinus sylvestris* Remaining inventory Unteres Ertragsniveau Mittelhöhenbonität 18.

A	HG	HO	G	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*m²*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
30	6.6	7.8	19.4	5.8	7,317	12.8	1.0	6.4	0.5	6.9	50.6
35	7.7	9.0	21.2	7.3	5,129	22.2	1.8	11.1	0.9	12.0	61.7
40	8.8	10.1	22.8	8.8	3,754	34.8	3.0	17.4	1.5	18.9	71.0
45	9.9	11.2	24.1	10.4	2,850	52.2	4.6	26.1	2.3	28.4	80.9
50	10.9	12.2	25.3	12.0	2,233	73.7	6.7	36.9	3.3	40.2	89.8
55	11.8	13.1	26.2	13.6	1,795	99.8	9.2	49.9	4.6	54.5	97.8
60	12.7	14.0	27.0	15.3	1,476	132.7	12.5	66.3	6.3	72.6	107.1
65	13.6	14.8	27.7	16.9	1,236	169.0	16.2	84.5	8.1	92.6	114.5
70	14.3	15.5	28.2	18.5	1,052	210.2	20.5	105.1	10.3	115.3	121.3
75	15.1	16.2	28.6	20.0	908	254.3	25.1	127.1	12.6	139.7	126.8
80	15.8	16.9	28.9	21.6	793	306.4	30.6	153.2	15.3	168.5	133.6
85	16.4	17.5	29.2	23.0	700	356.7	36.1	178.4	18.0	196.4	137.5
90	17.0	18.0	29.3	24.5	623	415.6	42.5	207.8	21.2	229.0	142.7
95	17.5	18.5	29.4	25.9	560	475.1	49.1	237.5	24.5	262.1	146.8
100	18.0	18.9	29.5	27.2	507	534.9	55.7	267.4	27.9	295.3	149.7
105	18.4	19.3	29.5	28.5	462	598.2	62.9	299.1	31.4	330.5	152.7
110	18.8	19.6	29.4	29.7	424	660.7	70.0	330.3	35.0	365.3	154.9
115	19.1	19.9	29.3	30.9	391	725.9	77.6	363.0	38.8	401.7	157.1
120	19.4	20.2	29.2	32.0	362	789.2	84.9	394.6	42.5	437.1	158.2
125	19.7	20.4	29.1	33.1	338	855.7	92.7	427.8	46.4	474.2	160.3
130	19.9	20.6	28.9	34.1	316	918.1	100.1	459.0	50.1	509.1	160.9
135	20.0	20.7	28.7	35.1	297	981.7	107.9	490.9	54.0	544.8	161.8
140	20.1	20.8	28.5	36.0	280	1041.3	115.3	520.7	57.6	578.3	161.9

Table 31. Biomass and Carbon estimates for *Pinus sylvestris*. Remaining inventory Unteres Ertragsniveau Mittelhöhenbonität 20.

A	HG	HO	G	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*m²*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
30	7.7	9.0	20.8	6.9	5,629	19.5	1.6	9.8	0.8	10.6	59.4
35	8.9	10.3	22.7	8.5	4,036	32.2	2.7	16.1	1.4	17.5	70.6
40	10.2	11.5	24.3	10.1	3,011	49.1	4.3	24.5	2.1	26.7	80.3
45	11.3	12.7	25.7	11.9	2,322	72.9	6.5	36.4	3.3	39.7	92.2
50	12.4	13.7	26.9	13.6	1,843	100.8	9.2	50.4	4.6	55.0	101.4
55	13.4	14.7	27.8	15.4	1,498	136.3	12.7	68.1	6.4	74.5	111.6
60	14.4	15.7	28.6	17.1	1,243	176.0	16.7	88.0	8.4	96.3	119.7
65	15.3	16.5	29.3	18.8	1,050	221.6	21.4	110.8	10.7	121.5	127.6
70	16.1	17.3	29.8	20.5	900	273.3	26.8	136.6	13.4	150.0	135.0

A	HG	HO	G	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*m²*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
75	16.9	18.0	30.2	22.2	782	331.6	32.9	165.8	16.5	182.3	142.5
80	17.6	18.7	30.5	23.8	686	392.5	39.4	196.3	19.7	216.0	148.2
85	18.3	19.3	30.7	25.4	609	459.8	46.7	229.9	23.3	253.2	154.2
90	18.9	19.9	30.9	26.9	545	528.3	54.1	264.1	27.1	291.2	158.7
95	19.5	20.4	31.0	28.3	492	597.8	61.8	298.9	30.9	329.8	162.2
100	20.0	20.9	31.0	29.7	447	671.6	70.0	335.8	35.0	370.8	165.8
105	20.5	21.3	31.0	31.1	409	750.7	78.9	375.3	39.4	414.8	169.6
110	20.9	21.7	31.0	32.4	377	828.1	87.7	414.1	43.9	457.9	172.6
115	21.2	22.0	30.9	33.6	349	902.9	96.4	451.5	48.2	499.6	174.4
120	21.5	22.3	30.7	34.7	324	975.1	104.8	487.6	52.4	540.0	174.9
125	21.8	22.5	30.6	35.8	303	1050.7	113.6	525.4	56.8	582.2	176.4
130	22.0	22.7	30.4	36.9	285	1128.2	122.9	564.1	61.4	625.6	178.3
135	22.2	22.8	30.2	37.8	269	1194.6	130.8	597.3	65.4	662.7	178.3
140	22.3	22.9	30.0	38.8	254	1269.1	140.0	634.6	70.0	704.5	179.0

Table 32. Biomass and Carbon estimates for *Pinus sylvestris*. Remaining inventory Mittleres Ertragsniveau Mittelhöhenbonität 18.

A	HG	HO	G	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*m²*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
30	6.6	7.9	20.4	5.5	8,613	11.4	0.9	5.7	0.4	6.1	52.7
35	7.7	9.1	22.3	6.9	6,009	19.5	1.6	9.8	0.8	10.6	63.4
40	8.8	10.2	24.0	8.3	4,384	30.5	2.6	15.2	1.3	16.5	72.4
45	9.9	11.3	25.4	9.9	3,320	46.6	4.1	23.3	2.0	25.3	84.1
50	10.9	12.3	26.6	11.4	2,596	65.6	5.8	32.8	2.9	35.7	92.7
55	11.8	13.2	27.6	13.0	2,084	90.0	8.2	45.0	4.1	49.1	102.3
60	12.7	14.0	28.4	14.5	1,711	117.3	10.9	58.7	5.5	64.1	109.7
65	13.6	14.9	29.1	16.1	1,432	151.3	14.3	75.7	7.2	82.8	118.6
70	14.3	15.6	29.7	17.6	1,218	187.6	18.0	93.8	9.0	102.8	125.2
75	15.1	16.3	30.1	19.1	1,050	229.0	22.3	114.5	11.1	125.6	131.9
80	15.8	16.9	30.4	20.6	917	275.0	27.1	137.5	13.6	151.1	138.5
85	16.4	17.5	30.7	22.0	809	322.4	32.1	161.2	16.1	177.3	143.4
90	17.0	18.1	30.9	23.4	721	374.3	37.7	187.2	18.9	206.0	148.5
95	17.5	18.5	31.0	24.7	647	426.5	43.4	213.2	21.7	234.9	152.0
100	18.0	19.0	31.0	26.0	586	482.7	49.6	241.4	24.8	266.1	156.0
105	18.4	19.4	31.0	27.2	534	537.9	55.7	269.0	27.9	296.8	158.5
110	18.8	19.7	31.0	28.4	490	596.7	62.3	298.4	31.2	329.5	161.5
115	19.1	20.0	30.9	29.5	451	653.3	68.8	326.6	34.4	361.0	162.8
120	19.4	20.3	30.8	30.6	419	712.9	75.6	356.4	37.8	394.3	165.2
125	19.7	20.5	30.6	31.6	390	770.0	82.2	385.0	41.1	426.1	166.2
130	19.9	20.6	30.4	32.6	365	828.8	89.1	414.4	44.6	458.9	167.5

A	HG	HO	G	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*m²*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
135	20.0	20.8	30.2	33.5	343	882.9	95.6	441.4	47.8	489.3	167.8
140	20.1	20.8	30.0	34.3	324	932.8	101.7	466.4	50.8	517.2	167.6

Table 33. Biomass and Carbon estimates for *Pinus sylvestris*. Remaining inventory Mittleres Ertragsniveau Mittelhöhenbonität 20.

A	HG	HO	G	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*m²*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
30	7.7	9	21.9	6.6	6,460	17.6	1.4	8.8	0.7	9.5	61.5
35	8.9	10.4	23.9	8.1	4,616	28.9	2.4	14.4	1.2	15.6	72.2
40	10.2	11.6	25.6	9.7	3,435	44.7	3.8	22.4	1.9	24.3	83.4
45	11.3	12.7	27.1	11.4	2,645	66.1	5.8	33.0	2.9	36.0	95.1
50	12.4	13.8	28.3	13.1	2,096	92.6	8.4	46.3	4.2	50.5	105.8
55	13.4	14.8	29.3	14.8	1,702	124.5	11.5	62.2	5.7	68.0	115.7
60	14.4	15.7	30.1	16.5	1,411	162.2	15.2	81.1	7.6	88.7	125.2
65	15.3	16.6	30.8	18.2	1,191	205.8	19.7	102.9	9.8	112.7	134.3
70	16.1	17.4	31.4	19.8	1,020	252.5	24.5	126.3	12.2	138.5	141.3
75	16.9	18.1	31.8	21.4	885	305.1	29.9	152.5	15.0	167.5	148.2
80	17.6	18.8	32.1	22.9	777	359.6	35.7	179.8	17.8	197.7	153.6
85	18.3	19.4	32.4	24.4	690	419.7	42.0	209.9	21.0	230.9	159.3
90	18.9	20	32.5	25.9	617	484.8	49.1	242.4	24.5	266.9	164.7
95	19.5	20.5	32.6	27.3	557	550.9	56.3	275.5	28.1	303.6	169.1
100	20	20.9	32.7	28.7	506	621.4	64.0	310.7	32.0	342.7	173.4
105	20.5	21.4	32.6	30	463	691.8	71.8	345.9	35.9	381.8	176.8
110	20.9	21.7	32.6	31.2	426	760.2	79.5	380.1	39.8	419.9	178.9
115	21.2	22	32.5	32.4	394	831.4	87.7	415.7	43.9	459.6	181.1
120	21.5	22.3	32.4	33.5	367	900.3	95.6	450.2	47.8	498.0	182.8
125	21.8	22.6	32.2	34.6	343	972.5	104.0	486.3	52.0	538.3	184.6
130	22	22.7	32	35.6	322	1040.1	112.0	520.0	56.0	576.0	185.5
135	22.2	22.9	31.8	36.5	304	1103.5	119.5	551.7	59.7	611.5	185.9
140	22.3	23	31.6	37.4	288	1167.6	127.2	583.8	63.6	647.4	186.5

Table 34. Biomass and Carbon estimates for *Picea abies*. Remaining inventory Fichte Mässige V.Ertrags.

A	HG	HO	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
40	4.5	5.2	6.8	4,880	32.5	0.8	16.2	0.4	16.6	81.1
45	5.6	6.7	7.7	4,345	52.6	1.1	26.3	0.6	26.9	116.7
50	6.8	8.3	8.5	3,795	79.6	1.5	39.8	0.7	40.5	153.8

A	HG	HO	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
55	8	9.8	9.4	3,350	119.3	1.9	59.6	1.0	60.6	203.1
60	9.3	11.3	10.3	2,965	173.7	2.5	86.8	1.3	88.1	261.2
65	10.5	12.7	11.2	2,630	242.7	3.2	121.3	1.6	122.9	323.3
70	11.7	14	12.1	2,335	330.0	3.9	165.0	2.0	167.0	389.9
75	12.8	15.2	12.9	2,100	426.3	4.7	213.1	2.3	215.5	452.5
80	13.8	16.2	13.7	1,900	538.6	5.6	269.3	2.8	272.1	516.9
85	14.8	17.3	14.4	1,738	658.1	6.4	329.0	3.2	332.2	577.4
90	15.7	18.2	15	1,578	776.8	7.2	388.4	3.6	392.0	618.6
95	16.5	19	15.7	1,442	922.8	8.1	461.4	4.1	465.5	671.2
100	17.2	19.7	16.3	1,325	1063.9	9.0	532.0	4.5	536.5	710.8

Table 35. Biomass and Carbon estimates for *Picea abies*. Remaining inventory Fichte Mässige IV.Ertrags.

A	HG	HO	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
30	4.2	4.7	6.3	5,917	25.4	0.6	12.7	0.3	13.0	76.9
35	5.5	6.6	7.2	4,718	43.2	0.9	21.6	0.5	22.1	104.1
40	4.2	4.7	6.3	5,917	25.4	0.6	12.7	0.3	13.0	76.9
45	5.5	6.6	7.2	4,718	43.2	0.9	21.6	0.5	22.1	104.1
50	6.9	8.4	8.3	3,870	75.3	1.4	37.6	0.7	38.3	148.3
55	8.3	10.1	9.4	3,370	122.7	1.9	61.4	1.0	62.3	210.1
60	9.8	11.9	10.6	2,977	196.4	2.7	98.2	1.4	99.6	296.4
65	11.3	13.6	11.7	2,635	291.5	3.6	145.8	1.8	147.6	388.8
70	12.7	15.1	12.8	2,355	414.2	4.6	207.1	2.3	209.4	493.2
75	14	16.5	13.8	2,097	556.4	5.7	278.2	2.8	281.1	589.4
80	15.2	17.7	14.9	1,862	741.9	7.0	371.0	3.5	374.5	697.3
85	16.3	18.9	15.9	1,670	947.4	8.4	473.7	4.2	477.9	798.1
90	17.3	19.9	16.8	1,509	1166.2	9.8	583.1	4.9	588.0	887.3
95	18.3	20.9	17.8	1,365	1443.5	11.5	721.8	5.8	727.5	993.1
100	19.2	21.7	18.7	1,232	1732.1	13.2	866.1	6.6	872.7	1,075.2
105	20.1	22.6	19.5	1,120	2030.9	14.9	1015.5	7.4	1,022.9	1,145.6
110	21	23.5	20.4	1,023	2399.9	16.9	1200.0	8.4	1,208.4	1,236.2
115	21.8	24.2	21.2	942	2767.4	18.8	1383.7	9.4	1,393.1	1,312.3
120	22.6	25	21.9	867	3133.1	20.6	1566.6	10.3	1,576.8	1,367.1
125	23.3	25.6	22.6	800	3520.6	22.5	1760.3	11.2	1,771.6	1,417.2
130	24	26.3	23.2	735	3893.4	24.2	1946.7	12.1	1,958.8	1,439.7

Table 36. Biomass and Carbon estimates for *Picea abies*. Fichte Gestaffelte Durchforstung III.Ertrags.

A	HG	HO	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	*m*	*m*	*cm*	*trees/ ha*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*tn/ha*
20	3.7	3.8	4.1	5,917	7.7	0.2	3.9	0.1	4.0	23.5
25	5.5	6.5	6.1	4,617	27.5	0.6	13.7	0.3	14.0	64.8
30	7	8.4	7.8	3,667	64.0	1.2	32.0	0.6	32.6	119.5
35	8.6	10.3	9.5	2,887	130.0	2.0	65.0	1.0	66.0	190.5
40	10	11.9	11	2,392	221.7	3.0	110.9	1.5	112.4	268.8
45	12.1	14.2	13	2,002	380.7	4.4	190.3	2.2	192.5	385.5
50	13.9	16.1	14	1,692	612.6	6.3	306.3	3.1	309.4	523.5
55	15.5	17.7	16	1,454	908.8	8.4	454.4	4.2	458.6	666.8
60	17	19.3	18	1,266	1293.0	11.0	646.5	5.5	652.0	825.5
65	18.4	20.6	19	1,110	1777.5	14.1	888.8	7.0	895.8	994.3
70	19.6	21.8	21	984	2331.3	17.4	1165.6	8.7	1,174.3	1,155.5
75	20.7	22.9	22	879	2990.6	21.1	1495.3	10.6	1,505.9	1,323.7
80	21.8	23.9	24	791	3731.3	25.1	1865.6	12.5	1,878.2	1,485.6
85	22.8	24.9	25	715	4582.2	29.5	2291.1	14.7	2,305.8	1,648.7
90	23.7	25.7	26	649	5486.9	34.0	2743.5	17.0	2,760.5	1,791.5
95	24.5	26.4	28	590	6563.5	39.3	3281.8	19.6	3,301.4	1,947.8
100	25.4	27.3	29	539	7812.2	45.1	3906.1	22.6	3,928.7	2,117.5
105	26.3	28.1	30	494	9226.8	51.5	4613.4	25.7	4,639.1	2,291.7
110	27.1	28.8	32	453	10787.6	58.3	5393.8	29.2	5,423.0	2,456.6
115	27.7	29.4	33	417	12458.8	65.8	6229.4	32.9	6,262.3	2,611.4
120	28.3	29.9	35	384	14309.7	73.9	7154.9	36.9	7,191.8	2,761.6

Table 37. Biomass and Carbon estimates for *Picea abies*. Remaining inventory Fichte Gestaffelte Durchforstung II.Ertrags

A	HG	HO	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	m	m	cm	trees/ ha	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	tn/ha
20	4.9	5.6	5.2	5,917	16.7	0.4	8.3	0.2	8.5	50.4
25	7.2	8.6	7.8	3,594	65.4	1.2	32.7	0.6	33.3	119.5
30	9.2	11	10	2,794	158.4	2.3	79.2	1.2	80.4	224.5
35	11.4	13.4	12	2,204	308.1	3.7	154.1	1.9	155.9	343.7
40	13.7	15.8	14	1,795	535.4	5.6	267.7	2.8	270.5	485.5
45	15.8	18	16	1,517	858.1	7.8	429.0	3.9	433.0	656.8
50	17.9	20.2	17	1,303	1305.5	10.7	652.7	5.3	658.1	857.5
55	19.8	22.1	19	1,127	1889.0	14.1	944.5	7.0	951.5	1,072.4
60	21.5	23.7	21	987	2625.1	18.1	1312.5	9.0	1,321.6	1,304.4
65	23	25.2	23	867	3527.8	22.8	1763.9	11.4	1,775.3	1,539.2
70	24.2	26.3	25	760	4647.8	28.5	2323.9	14.2	2,338.1	1,777.0

A	HG	HO	DG	N	ABG	BGB	ABG C	BGB C	Total Carbon	
years	m	m	cm	trees/ ha	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	*kg/tree*	tn/ha
75	25.3	27.3	26	678	5,857.2	34.3	2,928.6	17.2	2,945.8	1,997.2
80	26.3	28.3	28	610	7,335.0	41.3	3,667.5	20.7	3,688.1	2,249.8
85	27.3	29.2	30	553	8,891.3	48.2	4,445.7	24.1	4,469.8	2,471.8
90	28.4	30.2	31	501	10,807.9	56.3	5,403.9	28.2	5,432.1	2,721.5
95	29.2	30.9	33	456	12,901.0	65.3	6,450.5	32.6	6,483.1	2,956.3
100	30.1	31.8	35	416	15,315.5	75.0	7,657.7	37.5	7,695.3	3,201.2
105	30.9	32.5	37	379	17,995.3	85.7	8,997.7	42.9	9,040.5	3,426.4
110	31.6	33.1	38	350	20,785.2	96.7	10,392.6	48.3	10,440.9	3,654.3
115	32.1	33.5	40	325	23,753.2	108.4	11,876.6	54.2	11,930.8	3,877.5
120	32.6	33.9	41	302	27,012.3	121.1	13,506.1	60.5	13,566.7	4,097.1

5.1.3 Carbon sequestration capacity simulations

Using simulated forest growth and values of future biomass and carbon sequestration capacity of selected species (Figure 6, Figure 5) one-time point was selected (~50 years). The tables presented in Figure 6 and Figure 7 show the carbon sequestration for the test sites in Germany. For these areas, two species were proposed as indicated in chapter 5.1.1 The Carbon values are given by ML type and by species combination in tones by ha [t/ha] and for all the surface of the ML in kilotonnes by ha [kt/ha]. Here, we observe that the main carbon fixing species is *Picea abies* sequestering 148.3 C t/ha whereas *Pinus sylvestris* captures 109.7 C t /ha in the case of ML1 class. If we observe the amount of carbon fixed for the whole ML area, planting only *Picea abies* would fix 996.1 Kilotonnes of Carbon in Wezlow and 2,313.7 kilotonnes of Carbon in the Nochte test site. On the other hand planting the whole surface of the ML with *Pinus sylvestris*, 655.7 kilotonnes of Carbon in Wezlow, and 1,579.9 kilotonnes of Carbon in Nochte would be fixed. Although maximizing the carbon intake of the ML would be better than the plantation of one species, it is encouraged to apply a mixture of *Picea abies* in and *Pinus sylvestris* to enhance biodiversity, resilience against disturbances such as forest fires, extreme weather events, and pest. The percentage of specific species should depend on forestry recommendations within the country.

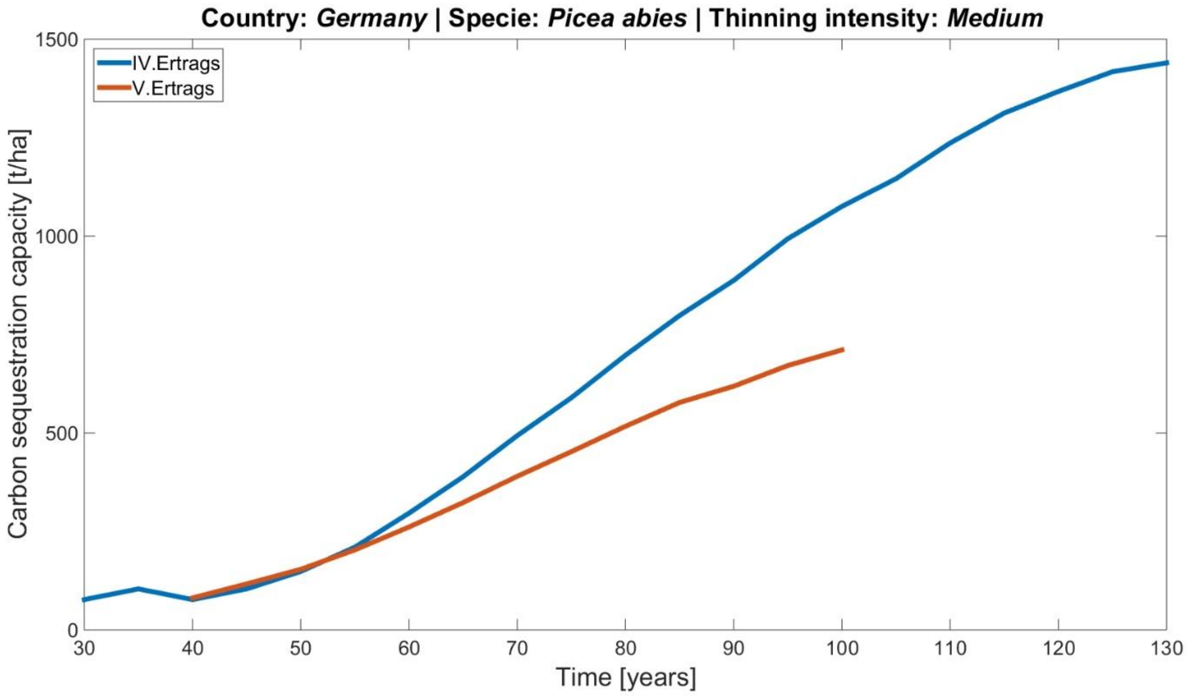

Figure 4. Simulation of carbon sequestration capacity of *Picea abies* in Germany.

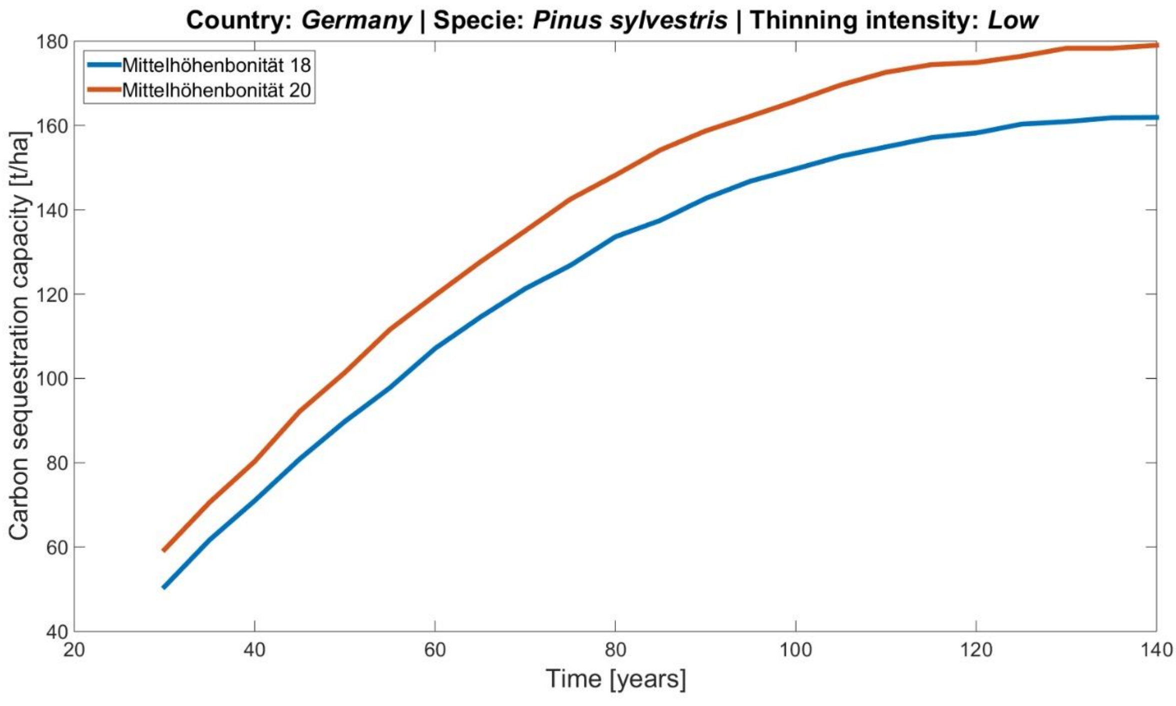

Figure 5. Simulation of carbon sequestration capacity of *Pinus sylvestris* in Germany.

Germany | Welzow | method C

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	148.3	144.4	140.6	136.7	132.9	129.0	125.1	121.3	117.4	113.6	109.7
	CSC [kt/ML1]	234.5	228.4	222.3	216.2	210.1	204.0	197.9	191.8	185.6	179.5	173.4
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	153.8	148.2	142.5	136.9	131.2	125.6	120.0	114.3	108.7	103.0	97.4
	CSC [kt/ML2]	761.6	733.7	705.8	677.8	649.9	622.0	594.0	566.1	538.2	510.3	482.3
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:Mittelhöhenbonität 20 | after thinning + thinning | low thinning intensity | age 50
ML1:Picea abies:IV.Ertrags | after thinning | medium intensity | no other data available | age 50
ML2:Pinus sylvestris:Mittelhöhenbonität 18 | after thinning + thinning | low thinning intensity | age 50
ML2:Picea abies:V.Ertrags | after thinning | medium intensity | no other data available | age 50

Figure 6. Carbon sequestration capacity of mixed species in "Welzow" test site.

Germany | Nochte | method C

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	148.3	144.4	140.6	136.7	132.9	129.0	125.1	121.3	117.4	113.6	109.7
	CSC [kt/ML1]	286.7	279.3	271.8	264.3	256.9	249.4	241.9	234.5	227.0	219.6	212.1
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	153.8	148.2	142.5	136.9	131.2	125.6	120.0	114.3	108.7	103.0	97.4
	CSC [kt/ML2]	2159.9	2080.7	2001.5	1922.3	1843.1	1763.9	1684.7	1605.5	1526.2	1447.0	1367.8
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:Mittelhöhenbonität 20 | after thinning + thinning | low thinning intensity | age 50
ML1:Picea abies:IV.Ertrags | after thinning | medium intensity | no other data available | age 50
ML2:Pinus sylvestris:Mittelhöhenbonität 18 | after thinning + thinning | low thinning intensity | age 50
ML2:Picea abies:V.Ertrags | after thinning | medium intensity | no other data available | age 50

Figure 7. Carbon sequestration capacity of mixed species in "Nochte" test site.

5.2 Poland

The test site selected for Poland was “Staszów” - the region within Staszów County part of Świętokrzyskie Voivodeship (Figure 8). The size and the whole region are divided into industrial (north) and rural (south) parts. Local deposits of gypsum stone are one of the largest in Europe. 50% of national lime production and 25% of national cement production come from this Voivodeship. According to the official data, the area of devastated land was increasing between 2004 and 2012. This region includes upland and lowland areas, strongly fragmented croplands, and low productivity lands that could be defined as potential Marginal Lands.

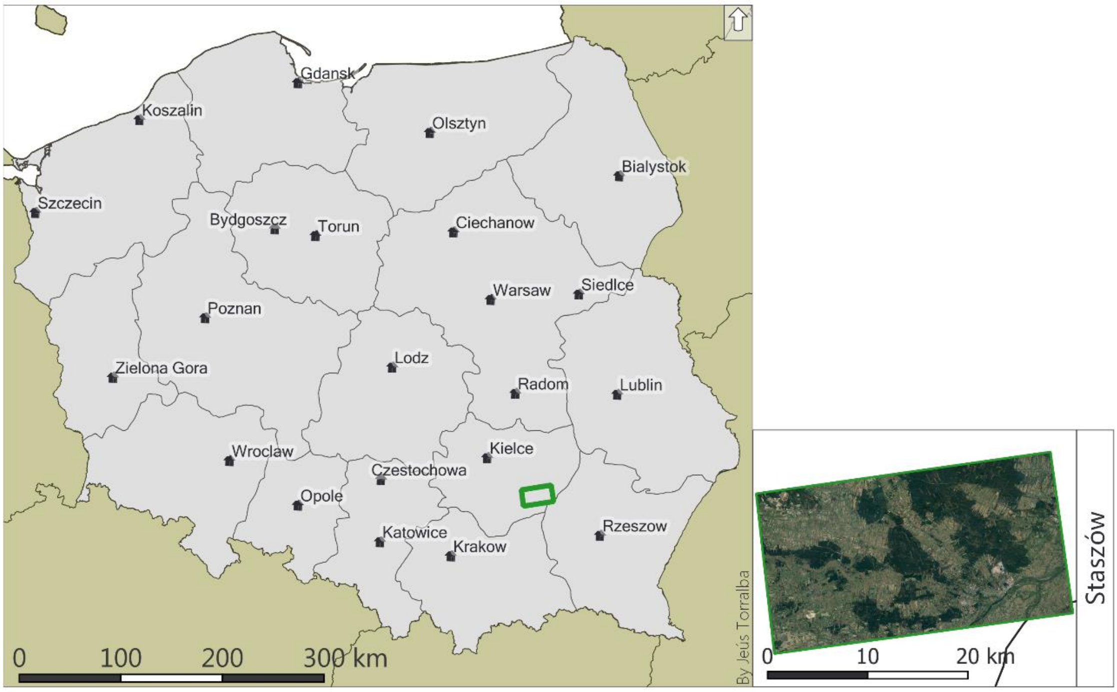

Figure 8. Poland (left) and the corresponding selected pilot site (outlined with green).

5.2.1 *Species selection*

The species composition for the Polish modules was based on the information extracted from the Polish National Inventory. The inventory provides spatially referenced data for all the forest plots. In our study site, the species composition of each plot was analyzed and plotted. Table 38 represents the area representation of every species in the marginal lands:

Table 38. Area distribution for the main species in the Polish test site according to the Polish Forest Data Bank.

Species CD	Scientific name	Area [ha]	%	Frequency
SO	*Pinus sylvestris*	7,101.43	76.67	2271
DB	*Quercus species*	1031.29	11.13	301
OL	*Alnus glutinosa*	538.84	5.82	260
BRZ	*Betula pendula*	253.70	2.74	124
JD	*Abies alba*	90.16	0.97	28
BK	*Fagus sylvatica*	63.10	0.68	17
MD	*Larix decidua*	49.66	0.54	16
DB.S	*Quercus robur*	23.78	0.26	7
OS	*Populus tremula*	22.83	0.25	18
ŚW	*Picea abies*	22.07	0.24	23
DB.C	*Quercus rubra*	15.67	0.17	7
GB	*Pyrus communis*	11.62	0.13	9
WB	*Salix alba*	8.43	0.09	6
DB.B	*Quercus petraea*	7.56	0.08	4
KRU	*Rhamnus frangula*	7.01	0.08	8
AK	*Robinia pseudoacacia*	4.00	0.04	6
ŚL.T	*Prunus spinosa*	3.60	0.04	5
JS	*Fraxinus excelsior*	3.39	0.04	3
JW	*Acer pseudoplatanus*	1.47	0.02	2
LP	*Tilia cordata*	1.41	0.02	3
KL	*Acer platanoides*	0.73	0.01	1
CZM	*Prunus padus*	0.27	0.003	1
DG	*Pseudotsuga menziesii*	0.26	0.003	1
TP	*Populus alba*	0.13	0.001	1
	Total	**9,262.40**	**100**	**3,122**

The inventory (Figure 9) reflects that there is a high diversity for the species composition in the forest plots of the polish Pilot site, accounting for 24 species. However, only three species describe almost the totality of the study area (93.32%). As previously done in the other test sites, the more represented species were selected. *Pinus sylvestris* was the dominant species by occupying 76.67% of the forested area. Forest stands that presented a mixture of *Quercus* species in their composition (presumably *Quercus petraea, Quercus robur,* and *Quercus rubra*) meant 11.13% of the surface. Finally, the 5.82% is occupied by *Alnus glutinosa.*

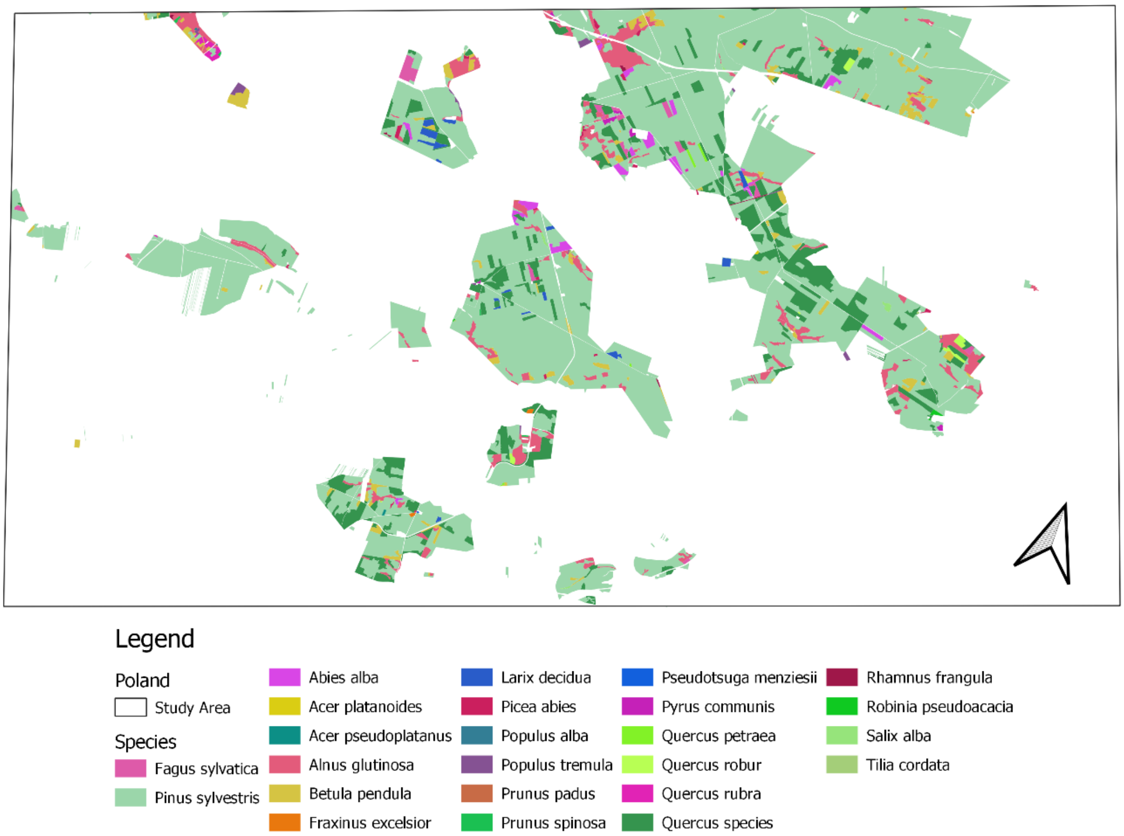

Figure 9. Species distribution in the Polish test site according to the Polish Forest Data Bank.

5.2.2 Biomass and carbon estimation by species

Biomass and carbon estimations were calculated for two species (*Pinus sylvestris, Quercus spp.)* and two ML classes (ML1 and ML2). Biomass and carbon values are presented (with division into ABG and BGB) in Table 39, Table 40, Table 41, and Table 42.Table 39. Biomass and Carbon estimates for *Pinus sylvestris* Class IV for ML1.

Table 39. Biomass and Carbon estimates for *Pinus sylvestris* Class IV for ML1.

Class IV - for ML1												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	***Total Biomass***	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees / ha	*m³/ ha*	*dm³/ tree*	*dm³/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/tree*	*kg/ha*
20	7600	50	6.58	7.43	3.13	0.61	3.74	28444.58	1.57	0.30	1.87	14222.29
25	5813	67	11.53	13.01	5.49	1.07	6.56	38115.74	2.75	0.53	3.28	19057.87
30	4508	88	19.52	22.04	9.30	1.81	11.11	50062.46	4.65	0.90	5.55	25031.23
35	3598	112	31.13	35.15	14.83	2.88	17.71	63715.86	7.41	1.44	8.85	31857.93
40	2983	137	45.93	51.85	21.88	4.25	26.13	77938.15	10.94	2.13	13.06	38969.07

Class IV - for ML1												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	***Total Biomass***	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees / ha	*m^3/ ha*	*dm^3/ tree*	*dm^3/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/tree*	*kg/ha*
45	2473	162	65.51	73.96	31.20	6.06	37.27	92160.44	15.60	3.03	18.63	46080.22
50	2079	186	89.47	101.01	42.62	8.28	50.90	105813.83	21.31	4.14	25.45	52906.92
55	1769	208	117.58	132.75	56.01	10.88	66.89	118329.45	28.00	5.44	33.45	59164.72
60	1524	228	149.61	168.91	71.26	13.85	85.11	129707.28	35.63	6.92	42.55	64853.64
65	1329	246	185.10	208.99	88.17	17.13	105.30	139947.33	44.08	8.57	52.65	69973.67
70	1171	262	223.74	252.61	106.57	20.71	127.28	149049.60	53.29	10.35	63.64	74524.80
75	1041	276	265.13	299.34	126.29	24.54	150.83	157014.08	63.14	12.27	75.42	78507.04
80	931	288	309.34	349.26	147.35	28.63	175.98	163840.78	73.68	14.32	87.99	81920.39
85	841	299	355.53	401.41	169.35	32.91	202.26	170098.58	84.68	16.45	101.13	85049.29
90	765	308	402.61	454.57	191.78	37.27	229.04	175218.61	95.89	18.63	114.52	87609.30
95	700	316	451.43	509.68	215.03	41.78	256.81	179769.74	107.52	20.89	128.41	89884.87
100	645	323	500.78	565.40	238.54	46.35	284.89	183751.98	119.27	23.18	142.44	91875.99
105	599	328	547.58	618.24	260.83	50.68	311.51	186596.44	130.42	25.34	155.76	93298.22
110	561	333	593.58	670.18	282.74	54.94	337.68	189440.90	141.37	27.47	168.84	94720.45
115	528	337	638.26	720.62	304.02	59.08	363.10	191716.46	152.01	29.54	181.55	95858.23
120	499	340	681.36	769.29	324.56	63.07	387.62	193423.14	162.28	31.53	193.81	96711.57

Table 40. Biomass and Carbon estimates for *Pinus sylvestris* Class V (worst bonitation) - for ML2.

Class V - for ML2												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	**Total Biomass**	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees/ ha	*m^3/ ha*	*dm^3/ tree*	*dm^3/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*
20												
25	7188	51	7.10	8.01	3.38	0.66	4.04	29013.47	1.69	0.33	2.02	14506.74
30	5590	66	11.81	13.33	5.62	1.09	6.72	37546.84	2.81	0.55	3.36	18773.42
35	4428	83	18.74	21.16	8.93	1.73	10.66	47218.00	4.46	0.87	5.33	23609.00
40	3648	103	28.23	31.88	13.45	2.61	16.06	58595.83	6.72	1.31	8.03	29297.92
45	3058	124	40.55	45.78	19.32	3.75	23.07	70542.56	9.66	1.88	11.53	35271.28
50	2598	144	55.43	62.58	26.40	5.13	31.53	81920.39	13.20	2.57	15.77	40960.19
55	2228	165	74.06	83.61	35.28	6.85	42.13	93867.11	17.64	3.43	21.07	46933.56
60	1928	183	94.92	107.17	45.21	8.79	54.00	104107.16	22.61	4.39	27.00	52053.58
65	1678	199	118.59	133.90	56.49	10.98	67.47	113209.43	28.25	5.49	33.73	56604.71
70	1476	212	143.63	162.17	68.42	13.29	81.71	120605.02	34.21	6.65	40.86	60302.51
75	1309	222	169.60	191.48	80.78	15.70	96.48	126293.93	40.39	7.85	48.24	63146.97
80	1164	231	198.45	224.06	94.53	18.37	112.90	131413.96	47.26	9.18	56.45	65706.98

Class V - for ML2												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	**Total Biomass**	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees/ ha	*m³/ ha*	*dm³/ tree*	*dm³/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*
85	1040	238	228.85	258.38	109.01	21.18	130.19	135396.20	54.50	10.59	65.09	67698.10
90	936	244	260.68	294.32	124.17	24.13	148.30	138809.55	62.09	12.06	74.15	69404.77
95	852	249	292.25	329.97	139.21	27.05	166.26	141654.00	69.60	13.53	83.13	70827.00
100	782	253	323.53	365.28	154.11	29.95	184.05	143929.57	77.05	14.97	92.03	71964.79
105	726	257	353.99	399.68	168.62	32.77	201.38	146205.14	84.31	16.38	100.69	73102.57
110	684	259	378.65	427.52	180.37	35.05	215.41	147342.92	90.18	17.52	107.71	73671.46
115	646	260	402.48	454.41	191.71	37.25	228.97	147911.81	95.86	18.63	114.48	73955.91
120	613	261	425.77	480.72	202.81	39.41	242.22	148480.70	101.41	19.70	121.11	74240.35

Table 41. Biomass and Carbon estimates for *Quercus species* Class III for ML1.

Class III - for ML1												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	**Total Biomass**	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees/ ha	*m³/ ha*	*dm³/ tree*	*dm³/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/tree*	*kg/ha*
20	11000	55	5.00	5.06	2.83	0.62	3.46	38024.69	1.42	0.31	1.73	19012.35
25	6600	72	10.91	11.04	6.18	1.36	7.54	49777.78	3.09	0.68	3.77	24888.89
30	4540	92	20.26	20.51	11.49	2.52	14.01	63604.94	5.74	1.26	7.00	31802.47
35	3290	113	34.35	34.77	19.47	4.27	23.75	78123.46	9.74	2.14	11.87	39061.73
40	2480	135	54.44	55.11	30.86	6.77	37.63	93333.33	15.43	3.39	18.82	46666.67
45	1930	159	82.38	83.40	46.70	10.25	56.96	109925.93	23.35	5.13	28.48	54962.96
50	1500	184	122.67	124.18	69.54	15.27	84.81	127209.88	34.77	7.63	42.40	63604.94
55	1240	208	167.74	169.81	95.10	20.87	115.97	143802.47	47.55	10.44	57.98	71901.23
60	1060	232	218.87	221.57	124.08	27.24	151.32	160395.06	62.04	13.62	75.66	80197.53
65	923	255	276.27	279.68	156.62	34.38	191.00	176296.30	78.31	17.19	95.50	88148.15
70	812	278	342.36	346.59	194.09	42.61	236.70	192197.53	97.05	21.30	118.35	96098.77
75	721	300	416.09	421.23	235.89	51.78	287.67	207407.41	117.94	25.89	143.83	103703.70
80	645	321	497.67	503.82	282.14	61.93	344.07	221925.93	141.07	30.97	172.04	110962.96
85	579	341	588.95	596.22	333.88	73.29	407.17	235753.09	166.94	36.65	203.59	117876.54
90	529	361	682.42	690.84	386.87	84.92	471.80	249580.25	193.44	42.46	235.90	124790.12
95	485	381	785.57	795.27	445.35	97.76	543.11	263407.41	222.67	48.88	271.55	131703.70
100	448	400	892.86	903.88	506.17	111.11	617.28	276543.21	253.09	55.56	308.64	138271.60
105	413	419	1014.53	1027.05	575.15	126.25	701.40	289679.01	287.57	63.13	350.70	144839.51
110	383	436	1138.38	1152.44	645.36	141.67	787.03	301432.10	322.68	70.83	393.51	150716.05
115	356	453	1272.47	1288.18	721.38	158.35	879.73	313185.19	360.69	79.18	439.87	156592.59
120	333	469	1408.41	1425.80	798.45	175.27	973.71	324246.91	399.22	87.63	486.86	162123.46
125	292	500	1712.33	1733.47	970.74	213.09	1183.83	345679.01	485.37	106.54	591.92	172839.51
130	259	530	2046.33	2071.60	1160.09	254.65	1414.75	366419.75	580.05	127.33	707.37	183209.88

Class III - for ML1												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	**Total Biomass**	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees/ ha	*m³/ ha*	*dm³/ tree*	*dm³/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/tree*	*kg/ha*
135	233	558	2394.85	2424.42	1357.67	298.03	1655.70	385777.78	678.84	149.01	827.85	192888.89
140	212	585	2759.43	2793.50	1564.36	343.40	1907.76	404444.44	782.18	171.70	953.88	202222.22

Table 42. Biomass and Carbon estimates for *Quercus species* Class IV for ML2

Class IV - for ML2												
Age	**N**	**V (stem+ branch)**	**V (stem+ branch)**	**V (stem+ branch+ foliage)**	**AGB (weight)**	**BGB**	**Total Biomass**	**Total Biomass**	**C AGB**	**C BGB**	**Total C**	**Total C**
	trees/ ha	*m³/ ha*	*dm³/ tree*	*dm³/ tree*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*
20	16950	44	2.60	2.63	1.47	0.32	1.79	30419.75	0.74	0.16	0.90	15209.88
25	12000	62	5.17	5.23	2.93	0.64	3.57	42864.20	1.46	0.32	1.79	21432.10
30	8180	74	9.05	9.16	5.13	1.13	6.25	51160.49	2.56	0.56	3.13	25580.25
35	5550	88	15.86	16.05	8.99	1.97	10.96	60839.51	4.49	0.99	5.48	30419.75
40	4060	101	24.88	25.18	14.10	3.10	17.20	69827.16	7.05	1.55	8.60	34913.58
45	3170	116	36.59	37.04	20.75	4.55	25.30	80197.53	10.37	2.28	12.65	40098.77
50	2490	132	53.01	53.67	30.05	6.60	36.65	91259.26	15.03	3.30	18.33	45629.63
55	2000	149	74.50	75.42	42.24	9.27	51.51	103012.35	21.12	4.64	25.75	51506.17
60	1660	167	100.60	101.84	57.03	12.52	69.55	115456.79	28.52	6.26	34.78	57728.40
65	1390	186	133.81	135.46	75.86	16.65	92.51	128592.59	37.93	8.33	46.26	64296.30
70	1190	204	171.43	173.54	97.19	21.33	118.52	141037.04	48.59	10.67	59.26	70518.52
75	1050	222	211.43	214.04	119.86	26.31	146.17	153481.48	59.93	13.16	73.09	76740.74
80	936	240	256.41	259.58	145.36	31.91	177.27	165925.93	72.68	15.95	88.64	82962.96
85	832	258	310.10	313.92	175.80	38.59	214.39	178370.37	87.90	19.29	107.19	89185.19
90	754	275	364.72	369.22	206.77	45.39	252.15	190123.46	103.38	22.69	126.08	95061.73
95	688	292	424.42	429.66	240.61	52.82	293.43	201876.54	120.30	26.41	146.71	100938.27
100	628	309	492.04	498.11	278.94	61.23	340.17	213629.63	139.47	30.62	170.09	106814.81
105	580	326	562.07	569.01	318.64	69.95	388.59	225382.72	159.32	34.97	194.30	112691.36
110	538	342	635.69	643.54	360.38	79.11	439.49	236444.44	180.19	39.55	219.74	118222.22
115	500	357	714.00	722.81	404.78	88.85	493.63	246814.81	202.39	44.43	246.81	123407.41
120	468	371	792.74	802.52	449.41	98.65	548.06	256493.83	224.71	49.33	274.03	128246.91
125	409	409	1000.00	1012.35	566.91	124.44	691.36	282765.43	283.46	62.22	345.68	141382.72
130	360	437	1213.89	1228.88	688.17	151.06	839.23	302123.46	344.09	75.53	419.62	151061.73
135	320	463	1446.88	1464.74	820.25	180.06	1000.31	320098.77	410.13	90.03	500.15	160049.38
140	285	489	1715.79	1736.97	972.70	213.52	1186.22	338074.07	486.35	106.76	593.11	169037.04

5.2.3 Carbon sequestration capacity simulations

Using simulated forest growth and values of future biomass and carbon sequestration capacity of selected species (Figure 10, Figure 11) one-time point was selected (~50 years). The table presented in Figure 12 shows the carbon sequestration for the test site in Poland. For this area, two species were proposed as indicated in chapter 5.2.1 The Carbon values are given by ML type and by species combination in tones by ha [t/ha] and for all the surface of the ML in kilotonnes by ha [kt/ha]. Here, we observe that the main carbon fixing species is *Quercus spp.* sequestering 63.6 C t/ha whereas *Pinus sylvestris* captures 52.9 C t/ha in the case of ML1 class. If we observe the amount of carbon fixed for the whole ML area, planting only *Quercus spp.* would fix 77.9 kilotonnes of Carbon in Staszów test site. On the other hand, planting the whole surface of the ML with *Pinus sylvestris*, 69.9 kilotonnes of Carbon would be fixed. Although maximizing the carbon intake of the ML would be better for the plantation of one species, it is encouraged to apply a mixture of *Quercus spp.* in 70 % and *Pinus sylvestris* in 30% to enhance biodiversity, resilience against disturbances such as forest fires, extreme weather events, and pest.

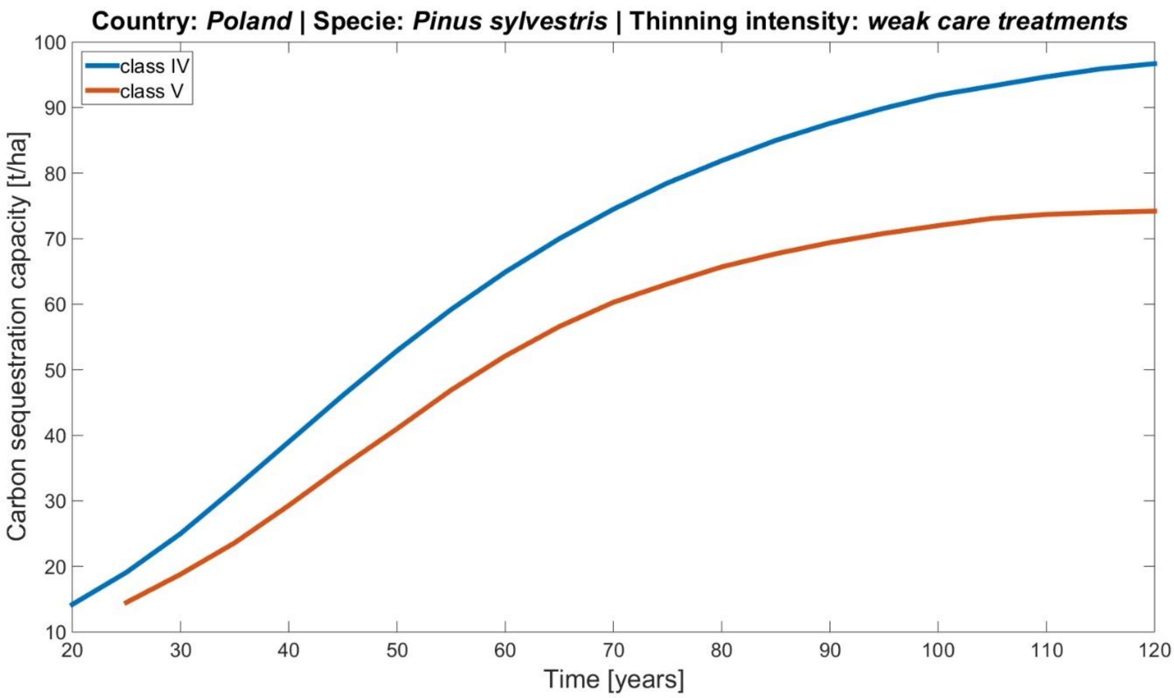

Figure 10. Simulation of carbon sequestration capacity of *Pinus sylvestris* in Poland.

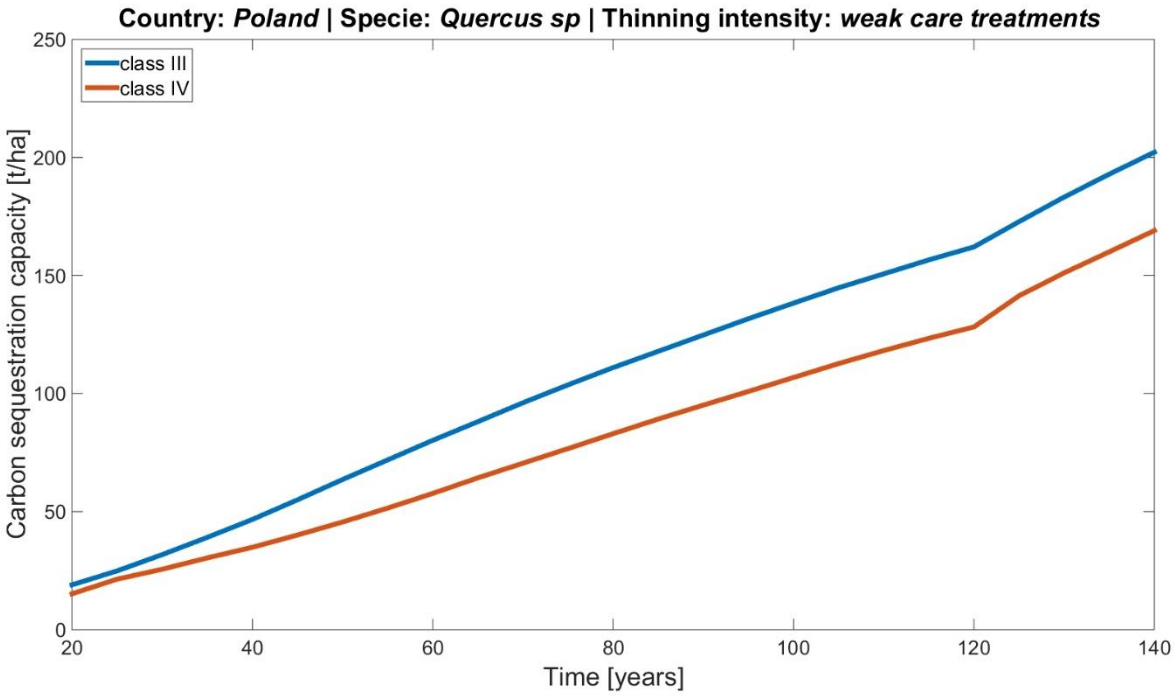

Figure 11. Simulation of carbon sequestration capacity of *Quercus spp.* in Poland.

Poland | Staszów | method C

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	63.6	62.5	61.5	60.4	59.3	58.3	57.2	56.1	55.0	54.0	52.9
	CSC [kt/ML1]	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	45.6	45.1	44.7	44.2	43.7	43.3	42.8	42.4	41.9	41.4	41.0
	CSC [kt/ML2]	76.7	75.9	75.2	74.4	73.6	72.8	72.0	71.3	70.5	69.7	68.9
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:class IV weak treatment | before thinning | age 50
ML1:Quercus species:class III and weak treatment | before thinning | age 50
ML2:Pinus sylvestris:class V weak treatment | before thinning | age 50
ML2:Quercus species:class IV and weak treatment | before thinning | age 50

Figure 12. Carbon sequestration capacity of mixed species in “Staszów” test site.

5.3 Spain

The Marginal lands proposed for Spain consist of several potential sites that could be defined as Marginal Lands including semi-urban degraded lands and low productivity lands adjacent to natural parks and forest areas. The test sites are “Tierras Altas” is located in Soria province of Castilla y León, the area of the Municipality of Nogueruelas (Teruel) in the Central Eastern part of the Iberian Peninsula, and “Sierra de Espadán” in the province of Castellón (region of Valencia) see Figure 13.

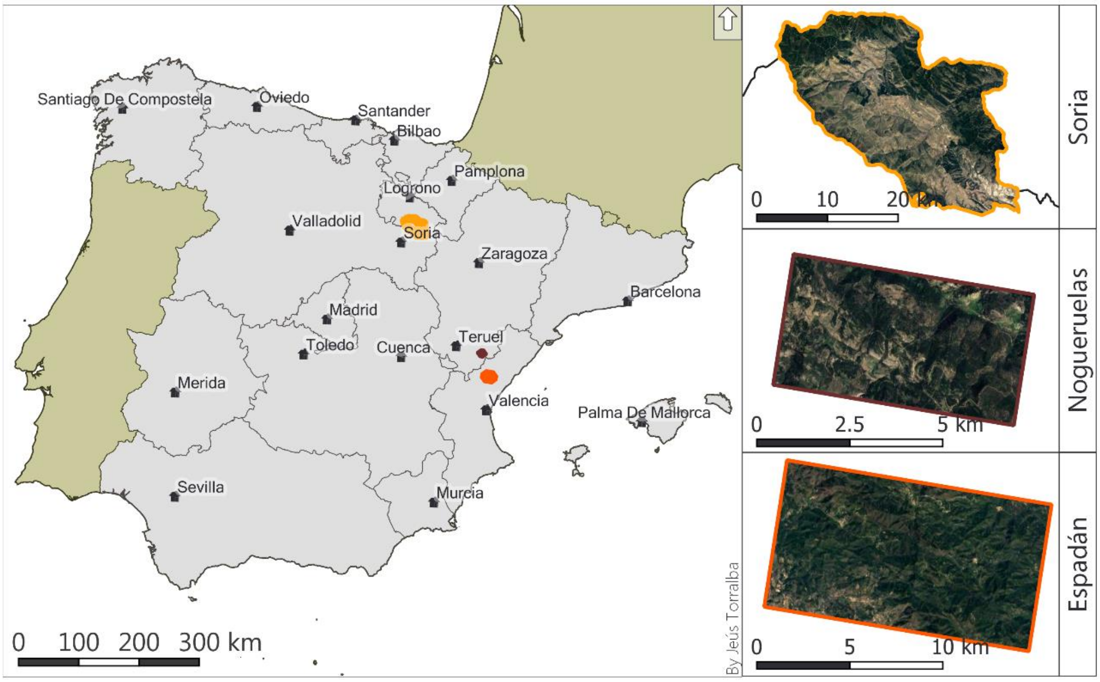

Figure 13. Spain (left) and the pilot site of “Soria” (outlined with light orange), “Nogueruelas” (outlined with dark red), and “Espadán” (right image outlined with dark orange).

5.3.1 Species selection

For the Spanish pilot sites, the national forest map was used (Figure 14, Figure 15, and Figure 16). This layer offers information about the structure and species composition for all the forest areas in Spain represented in tiles. For each pilot site, the current species composition was analyzed, and the most frequent species were selected for the reforestation module.

Soria: Tierras Altas

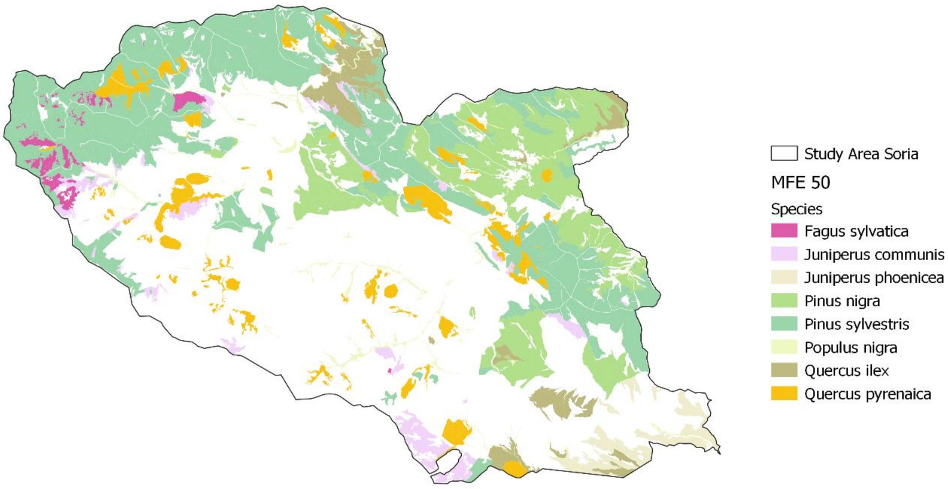

Figure 14. Species distribution for Tierras Altas, Soria. Source MFE50.

The species recurrence is summarized in Table 43:

Table 43. Area distribution for the main species in Tierras Altas, Soria according to the MFE50.

Species	Area [ha]	Area [%]	Frequency
Crataegus monogyna	29.91	0.11	1
Fagus sylvatica	552.46	1.95	35
Ilex aquifolium	304.50	1.08	12
Juniperus communis	1,307.99	4.62	47
Juniperus oxycedrus	39.25	0.14	2
Juniperus phoenicea	962.30	3.40	23
Juniperus thurifera	47.82	0.17	1
Pinus nigra	6,431.56	22.71	151
Pinus pinaster	14.66	0.05	2
Pinus sylvestris	13,410.31	47.36	313
Populus nigra	668.71	2.36	47
Populus x canadensis	65.31	0.23	3
Prunus avium	2.79	0.01	1
Quercus faginea	117.68	0.42	5
Quercus ilex	1,853.43	6.54	64
Quercus pyrenaica	2,484.21	8.77	117
Salix fragilis	9.33	0.03	1
Salix spp.	16.36	0.06	2
Total	**28,318.59**	**100.00**	**827**

The table reflects that the most represented species in the Sorian test site area are: *Pinus sylvestris, Pinus nigra,* and *Quercus pyrenaica.* Although *Quercus pyrenaica* is representative of the study area, the fact that it is more resource-demanding than the conifer species present in the test site deems this species as a less suitable candidate for entering the restauration module.

Castellón: Sierra de Espadán

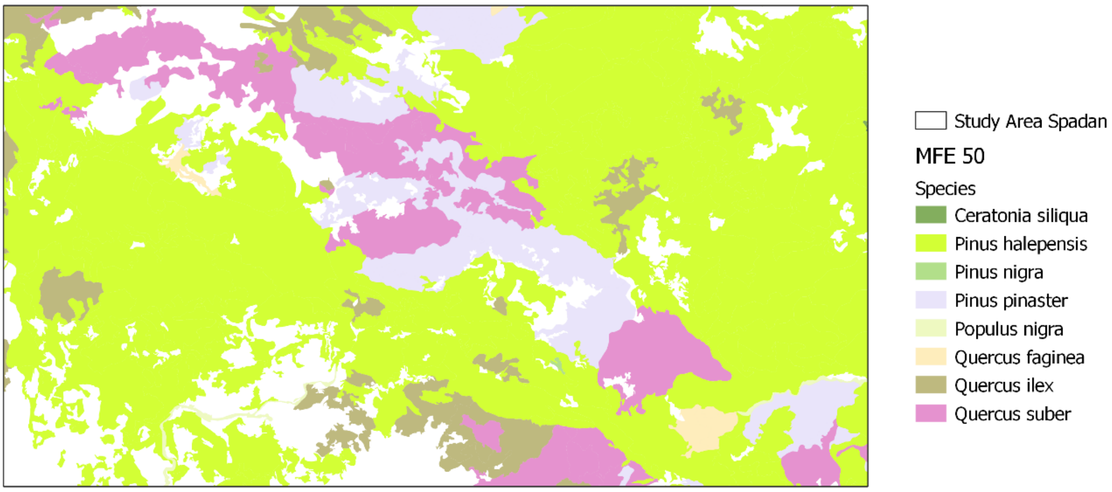

Figure 15. Species distribution in Sierra de Espadán, Castellón. Source MFE50.

The test site in la Sierra de Espadán is characterized by the presence of coniferous species (Table 44), mainly represented by *Pinus halepensis* (70%) and *Pinus pinaster* (10%), while broadleaves species are constituted by *Quercus suber* (12,30%) and *Quercus ilex* (6,41%). As previously argued before in the Soria test site (Tierras Altas), the marginal lands located in the Spanish Mediterranean sites are originated by environmental limitations rather than economic or social. Therefore, the species selection must prioritize the most resistant species to adverse ecological factors over more resource-demanding species. For this reason, coniferous species have been chosen for the reforestation module in Espadán. On a further note, *Quercus ilex,* despite its low representation in the area (6%), could be considered as potential species for reforestation in marginal lands, due to its endurance to both high and low temperatures and arid conditions during summer.

Table 44. Area distribution for the main species in Sierra de Espadán, Castellón according to the MFE50.

Species	Area [ha]	Area [%]	Frequency
Ceratonia siliqua	0.70	0.01	1
Pinus halepensis	6,786.63	70.04	156
Pinus nigra	2.45	0.03	1
Pinus pinaster	974.26	10.05	34
Populus nigra	36.55	0.38	4
Quercus faginea	75.75	0.78	4
Quercus ilex	621.57	6.41	24

Species	Area [ha]	Area [%]	Frequency
Quercus suber	1,192.37	12.30	27
Total	**9,690.28**	**100.00**	**251**

Teruel: Nogueruelas

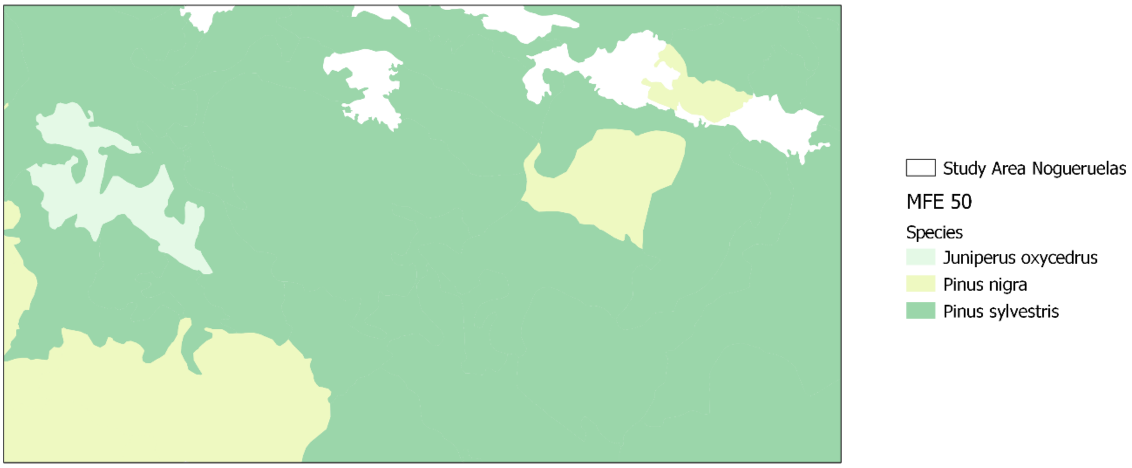

Figure 16. Species distribution in Nogueruelas, Teruel. Source MFE50.

As in other test sites in Spain, Nogueruela's test site is mainly populated by coniferous species. In this area, the species composition is led by *Pinus sylvestris* and followed by *Pinus nigra*. Additionally, scarce formations of *Juniperus oxycedrus* appear in the study area. Next, the species abundance and area distribution are summarized:

Table 45. Area distribution for the main species in Nogueruelas, Teruel according to the MFE50.

Species	Area [ha]	Area [%]	Frequency
Juniperus oxycedrus	71.91	3.21	1
Pinus nigra	331.97	14.83	10
Pinus sylvestris	1835.29	81.96	28
Total	**2239.17**	**100**	**39**

The species selected for the reforestation modules were *Pinus sylvestris* and *Pinus nigra* as they were the most abundant.

5.3.2 Biomass and carbon estimation by species

Next, all the carbon estimations by species are presented for the Spanish test sites. The carbon values are given in 3 pools, above-ground carbon, below-ground carbon, and total carbon per tree and hectare (Table 46, Table 47, Table 48, and Table 49). Additionally, the above-ground carbon is divided into values branches, foliage, and stem.

Table 46. Biomass and Carbon estimation for *Pinus pinaster* for the aboveground and belowground components and total tree.

Species	Quality	State	Age	N	V	V	ABG C (kg)/tree				C AGB	C BGB	Total C	Total C
			years	tree/ ha	m^3/ ha	dm^3/ tree	branch >7cm	branch 2-7cm	branch < 2cm	Stem	kg/ tree	kg/ tree	kg/ tree	kg/ ha
Pinus pinaster	12	Before thining	40	1500	92.8	61.9	0.2	1.1	2.9	16.4	20.7	5.9	26.5	39816.9
P. pinaster	12	Before thining	50	925	135.7	146.7	0.6	2.6	6.9	39.0	49.0	13.9	62.9	58223.7
P. pinaster	12	Before thining	65	550	178.0	323.6	1.3	5.7	15.1	86.0	108.2	30.7	138.9	76373.0
P. pinaster	12	Before thining	80	400	201.8	504.5	2.0	8.9	23.6	134.1	168.6	47.8	216.5	86584.6
P. pinaster	12	Thining	40	575	29.4	51.1	0.2	0.9	2.4	13.6	17.1	4.8	21.9	12614.4
P. pinaster	12	Thining	50	375	42.4	113.1	0.5	2.0	5.3	30.0	37.8	10.7	48.5	18192.2
P. pinaster	12	Thining	65	150	40.1	267.3	1.1	4.7	12.5	71.0	89.4	25.3	114.7	17205.4
P. pinaster	12	After thining	40	925	63.4	68.5	0.3	1.2	3.2	18.2	22.9	6.5	29.4	27202.5
P. pinaster	12	After thining	50	550	93.2	169.5	0.7	3.0	7.9	45.0	56.6	16.1	72.7	39988.5
P. pinaster	12	After thining	65	400	137.9	344.8	1.4	6.1	16.1	91.6	115.2	32.7	147.9	59167.6
P. pinaster	15	Before thinning	35	1500	119.4	79.6	0.7	2.0	2.1	22.5	31.5	8.6	40.1	60187.0
P. pinaster	15	Before thinning	45	925	182.8	197.6	1.8	5.0	5.2	55.8	78.3	21.3	99.6	92145.7
P. pinaster	15	Before thinning	60	550	245.9	447.1	4.0	11.4	11.9	126.3	177.1	48.2	225.4	123953.1
P. pinaster	15	Before thinning	75	350	279.6	798.9	7.2	20.3	21.2	225.7	316.5	86.2	402.7	140940.5
P. pinaster	15	Thinning	35	575	37.8	65.7	0.6	1.7	1.7	18.6	26.0	7.1	33.1	19054.2
P. pinaster	15	Thinning	45	375	57.2	152.5	1.4	3.9	4.1	43.1	60.4	16.5	76.9	28833.3
P. pinaster	15	Thinning	60	200	73.8	369.0	3.3	9.4	9.8	104.2	146.2	39.8	186.0	37201.0
P. pinaster	15	Stand after thinning	35	925	81.6	88.2	0.8	2.2	2.3	24.9	35.0	9.5	44.5	41132.9
P. pinaster	15	Stand after thinning	45	550	125.6	228.4	2.1	5.8	6.1	64.5	90.5	24.6	115.1	63312.3
P. pinaster	15	Stand after thinning	60	350	172.1	491.7	4.4	12.5	13.1	138.9	194.8	53.0	247.9	86752.0

Table 47. Biomass and Carbon estimation for *Pinus nigra* for the aboveground and belowground components and total tree.

Species	Quality	State	Age	N	V	V	ABG C (kg)/tree				C AGB	C BGB	Total C	Total C
			years	tree/ ha	m^3/ ha	dm^3/ tree	branch >7cm	branch 2-7cm	branch < 2cm	Stem	kg/ tree	kg/ tree	kg/ tree	kg/ ha
Pinus nigra	12	Before thining	40	1500	161.1	107.4	3.6	5.3	10.6	33.9	53.3	13.0	66.3	99424.1
P. nigra	12	Before thining	50	1000	233.7	233.7	7.8	11.5	23.0	73.8	116.0	28.3	144.2	144229.8
P. nigra	12	Before thining	65	650	263.1	404.8	13.5	19.9	39.8	127.7	200.8	49.0	249.8	162374.2
P. nigra	12	Before thining	80	425	234.2	551.1	18.3	27.1	54.1	173.9	273.4	66.7	340.1	144538.4
P. nigra	12	Thining	40	500	42.8	85.6	2.8	4.2	8.4	27.0	42.5	10.4	52.8	26414.4
P. nigra	12	Thining	50	350	62.3	178.0	5.9	8.7	17.5	56.2	88.3	21.5	109.9	38448.9
P. nigra	12	Thining	65	225	66.3	294.7	9.8	14.5	28.9	93.0	146.2	35.6	181.9	40917.6
P. nigra	12	After thining	40	1000	118.3	118.3	3.9	5.8	11.6	37.3	58.7	14.3	73.0	73009.8
P. nigra	12	After thining	50	650	171.3	263.5	8.8	12.9	25.9	83.2	130.8	31.9	162.6	105719.2
P. nigra	12	After thining	65	425	196.9	463.3	15.4	22.8	45.5	146.2	229.9	56.0	285.9	121518.4

Species	Quality	State	Age	N	V	V	ABG C (kg)/tree				C AGB	C BGB	Total C	Total C
			years	tree/ ha	m^3/ ha	dm^3/ tree	branch >7cm	branch 2-7cm	branch < 2cm	Stem	kg/ tree	kg/ tree	kg/ tree	kg/ ha
P. nigra	15	Before thinning	40	1500	220.0	146.7	1.3	3.7	3.9	41.4	58.1	15.8	73.9	110897.4
P. nigra	15	Before thinning	55	950	313.3	329.8	3.0	8.4	8.8	93.2	130.7	35.6	166.2	157928.0
P. nigra	15	Before thinning	70	600	338.6	564.3	5.1	14.3	15.0	159.4	223.6	60.9	284.5	170681.2
P. nigra	15	Before thinning	80	400	299.8	749.5	6.8	19.1	19.9	211.7	297.0	80.9	377.8	151122.9
P. nigra	15	Thinning	40	550	64.3	116.9	1.1	3.0	3.1	33.0	46.3	12.6	58.9	32412.3
P. nigra	15	Thinning	55	350	88.0	251.4	2.3	6.4	6.7	71.0	99.6	27.1	126.7	44359.0
P. nigra	15	Thinning	70	200	82.1	410.5	3.7	10.4	10.9	116.0	162.6	44.3	206.9	41384.9
P. nigra	15	Stand after thinning	40	950	155.6	163.8	1.5	4.2	4.3	46.3	64.9	17.7	82.6	78434.7
P. nigra	15	Stand after thinning	55	600	225.4	375.7	3.4	9.6	10.0	106.1	148.8	40.5	189.4	113619.4
P. nigra	15	Stand after thinning	70	400	256.5	641.3	5.8	16.3	17.0	181.1	254.1	69.2	323.2	129296.3

Table 48. Biomass and Carbon estimation for *Pinus sylvestris* for the aboveground and belowground components and total tree.

Species	Quality	State	Age	N	V	V	ABG C (kg)/tree				C AGB	C BGB	Total C	Total C
			years	tree/ ha	m^3/ ha	dm^3/ tree	branch >7cm	branch 2-7cm	branch < 2cm	Stem	kg/ tree	kg/ tree	kg/ tree	kg/ ha
Pinus sylvestris	12	Before thinning	40	1500	114.6	76.4	0.7	1.9	2.0	21.6	30.3	8.2	38.5	57767.5
P. sylvestris	12	Before thinning	55	1000	175.8	175.8	1.6	4.5	4.7	49.7	69.7	19.0	88.6	88617.1
P. sylvestris	12	Before thinning	70	625	182.8	292.5	2.6	7.4	7.8	82.6	115.9	31.6	147.4	92145.7
P. sylvestris	12	Before thinning	110	450	241	535.6	4.8	13.6	14.2	151.3	212.2	57.8	270.0	121483.1
P. sylvestris	12	Thinning	40	500	30.9	61.8	0.6	1.6	1.6	17.5	24.5	6.7	31.2	15576.0
P. sylvestris	12	Thinning	55	375	48.6	129.6	1.2	3.3	3.4	36.6	51.3	14.0	65.3	24498.2
P. sylvestris	12	Thinning	70	175	42.3	241.7	2.2	6.1	6.4	68.3	95.8	26.1	121.8	21322.5
P. sylvestris	12	Stand after thinning	40	1000	83.7	83.7	0.8	2.1	2.2	23.6	33.2	9.0	42.2	42191.4
P. sylvestris	12	Stand after thinning	55	625	127.2	203.5	1.8	5.2	5.4	57.5	80.6	22.0	102.6	64118.9
P. sylvestris	12	Stand after thinning	70	450	140.5	312.2	2.8	7.9	8.3	88.2	123.7	33.7	157.4	70823.1
P. sylvestris	15	Before thinning	35	1500	136.5	91.0	0.8	2.3	2.4	25.7	36.1	9.8	45.9	68806.8
P. sylvestris	15	Before thinning	50	950	214.7	226.0	2.0	5.7	6.0	63.8	89.5	24.4	113.9	108225.8
P. sylvestris	15	Before thinning	65	575	234.8	408.3	3.7	10.4	10.8	115.4	161.8	44.0	205.8	118357.8
P. sylvestris	15	Before thinning	110	400	315.2	788.0	7.1	20.0	20.9	222.6	312.2	85.0	397.2	158885.7
P. sylvestris	15	Thinning	35	550	40.4	73.5	0.7	1.9	2.0	20.8	29.1	7.9	37.0	20364.8
P. sylvestris	15	Thinning	50	375	62.4	166.4	1.5	4.2	4.4	47.0	65.9	18.0	83.9	31454.5
P. sylvestris	15	Thinning	65	175	59.1	337.7	3.1	8.6	9.0	95.4	133.8	36.4	170.2	29791.1
P. sylvestris	15	Stand after thinning	35	950	96.1	101.2	0.9	2.6	2.7	28.6	40.1	10.9	51.0	48442.0
P. sylvestris	15	Stand after thinning	50	575	152.3	264.9	2.4	6.7	7.0	74.8	104.9	28.6	133.5	76771.2
P. sylvestris	15	Stand after thinning	65	400	175.7	439.3	4.0	11.2	11.7	124.1	174.0	47.4	221.4	88566.7

Table 49. Biomass and Carbon estimation for *Pinus halepensis* for the aboveground and belowground components and total tree.

Species	Quality	State	Age	N	V	V	ABG C (kg)/tree				C AGB	C BGB	Total C	Total C
			years	*tree/ ha*	*m³/ ha*	*dm³/ tree*	*branch >7cm*	*branch 2-7cm*	*branch < 2cm*	*Stem*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*
Pinus halepensis	11	Before thining	20	2103	12.9	6.1	0.5	0.4	1.1	1.9	3.9	1.2	5	10618.9
P. halepensis	11	Before thining	30	2038	30.2	14.8	1.2	1	2.6	4.5	9.3	2.9	12.2	24859.9
P. halepensis	11	Before thining	40	1952	51.2	26.2	2.1	1.8	4.6	8	16.5	5.1	21.6	42146.5
P. halepensis	11	Before thining	50	1305	65.8	50.4	4.1	3.5	8.8	15.3	31.7	9.8	41.5	54164.9
P. halepensis	11	Before thining	60	1233	82.7	67.1	5.4	4.6	11.7	20.4	42.2	13	55.2	68076.5
P. halepensis	11	Before thining	70	1005	92.5	92	7.4	6.4	16.1	28	57.9	17.9	75.8	76143.6
P. halepensis	11	Before thining	80	862	100.3	116.4	9.4	8	20.3	35.4	73.2	22.6	95.8	82564.4
P. halepensis	11	Before thining	90	766	106.5	139	11.2	9.6	24.3	42.3	87.4	27	114.4	87668
P. halepensis	11	Before thining	100	699	111.5	159.5	12.8	11	27.9	48.6	100.3	31	131.3	91783.9
P. halepensis	11	Before thining	110	650	115.6	177.8	14.3	12.3	31.1	54.1	111.8	34.6	146.4	95158.9
P. halepensis	11	Before thining	120	613	118.9	194	15.6	13.4	33.9	59	122	37.7	159.7	97875.4
P. halepensis	11	Thining	20	65	0.1	1.5	0.1	0.1	0.3	0.5	1	0.3	1.3	82.3
P. halepensis	11	Thining	30	86	0.3	3.5	0.3	0.2	0.6	1.1	2.2	0.7	2.9	247
P. halepensis	11	Thining	40	647	3.6	5.6	0.4	0.4	1	1.7	3.5	1.1	4.6	2963.4
P. halepensis	11	Thining	50	72	4.5	62.5	5	4.3	10.9	19	39.3	12.1	51.4	3704.3
P. halepensis	11	Thining	60	227	9.3	41	3.3	2.8	7.2	12.5	25.8	8	33.7	7655.5
P. halepensis	11	Thining	70	143	13.7	95.8	7.7	6.6	16.7	29.2	60.3	18.6	78.9	11277.5
P. halepensis	11	Thining	80	96	17.6	183.3	14.8	12.7	32.1	55.8	115.3	35.6	150.9	14487.9
P. halepensis	11	Thining	90	67	21	313.4	25.2	21.7	54.8	95.4	197.1	60.9	258	17286.7
P. halepensis	11	Thining	100	49	23.8	485.7	39.1	33.6	84.9	147.8	305.5	94.4	399.8	19591.5
P. halepensis	11	Thining	110	37	26.2	708.1	57	49	123.8	215.5	445.3	137.6	582.9	21567.2
P. halepensis	11	Thining	120	–	–	–	–	–	–	–	–	–	–	–
P. halepensis	11	After thining	20	2038	13	6.4	0.5	0.4	1.1	1.9	4	1.2	5.3	10701.3
P. halepensis	11	After thining	30	1952	30.1	15.4	1.2	1.1	2.7	4.7	9.7	3	12.7	24777.5
P. halepensis	11	After thining	40	1305	47.1	36.1	2.9	2.5	6.3	11	22.7	7	29.7	38771.5
P. halepensis	11	After thining	50	1233	64.8	52.6	4.2	3.6	9.2	16	33.1	10.2	43.3	53341.7
P. halepensis	11	After thining	60	1005	77.5	77.1	6.2	5.3	13.5	23.5	48.5	15	63.5	63796
P. halepensis	11	After thining	70	862	87.8	101.9	8.2	7	17.8	31	64.1	19.8	83.8	72274.7
P. halepensis	11	After thining	80	766	96.1	125.5	10.1	8.7	21.9	38.2	78.9	24.4	103.3	79107
P. halepensis	11	After thining	90	699	102.9	147.2	11.9	10.2	25.7	44.8	92.6	28.6	121.2	84704.6
P. halepensis	11	After thining	100	650	108.5	166.9	13.4	11.5	29.2	50.8	105	32.4	137.4	89314.4
P. halepensis	11	After thining	110	613	113	184.3	14.8	12.8	32.2	56.1	115.9	35.8	151.7	93018.7
P. halepensis	11	After thining	120	–	–	–	–	–	–	–	–	–	–	–
P. halepensis	14	Before thining	20	1586	24.7	15.6	1.3	1.1	2.7	4.7	9.8	3	12.8	20332.4
P. halepensis	14	Before thining	30	1481	53.3	36	2.9	2.5	6.3	11	22.6	7	29.6	43875.2
P. halepensis	14	Before thining	40	1342	85	63.3	5.1	4.4	11.1	19.3	39.8	12.3	52.1	69969.8

Species	Quality	State	Age	N	V	V	ABG C (kg)/tree				C AGB	C BGB	Total C	Total C
			years	*tree/ ha*	*m^3/ ha*	*dm^3/ tree*	*branch >7cm*	*branch 2-7cm*	*branch < 2cm*	*Stem*	*kg/ tree*	*kg/ tree*	*kg/ tree*	*kg/ ha*
P. halepensis	14	Before thining	50	1006	107.1	106.5	8.6	7.4	18.6	32.4	67	20.7	87.6	88161.9
P. halepensis	14	Before thining	60	977	134.5	137.7	11.1	9.5	24.1	41.9	86.6	26.7	113.3	110716.9
P. halepensis	14	Before thining	70	797	147.2	184.7	14.9	12.8	32.3	56.2	116.2	35.9	152	121171.2
P. halepensis	14	Before thining	80	684	157.4	230.1	18.5	15.9	40.2	70	144.7	44.7	189.4	129567.6
P. halepensis	14	Before thining	90	608	165.5	272.2	21.9	18.8	47.6	82.9	171.2	52.9	224.1	136235.3
P. halepensis	14	Before thining	100	554	172	310.5	25	21.5	54.3	94.5	195.3	60.3	255.6	141585.9
P. halepensis	14	Before thining	110	515	177.3	344.3	27.7	23.8	60.2	104.8	216.5	66.9	283.4	145948.8
P. halepensis	14	Before thining	120	486	181.6	373.7	30.1	25.8	65.3	113.7	235	72.6	307.6	149488.4
P. halepensis	14	Thining	20	65	0.1	1.5	0.2	0.1	0.3	0.6	1.2	0.4	1.6	164.6
P. halepensis	14	Thining	30	86	0.3	3.5	0.7	0.6	1.5	2.6	5.4	1.7	7.1	987.8
P. halepensis	14	Thining	40	647	3.6	5.6	2	1.7	4.3	7.4	15.3	4.7	20.1	6750
P. halepensis	14	Thining	50	72	4.5	62.5	25.8	22.2	56.1	97.6	201.7	62.3	264	7655.5
P. halepensis	14	Thining	60	227	9.3	41	8.8	7.6	19.1	33.3	68.8	21.3	90.1	16216.5
P. halepensis	14	Thining	70	143	13.7	95.8	20.4	17.6	44.4	77.3	159.7	49.3	209.1	23625.1
P. halepensis	14	Thining	80	96	17.6	183.3	38.4	33	83.5	145.4	300.4	92.8	393.2	29881.2
P. halepensis	14	Thining	90	67	21	313.4	64.7	55.6	140.5	244.7	505.5	156.1	661.6	35067.2
P. halepensis	14	Thining	100	49	23.8	485.7	98.9	85	214.7	373.9	772.4	238.6	1011	39430
P. halepensis	14	Thining	110	37	26.2	708.1	145.5	125	315.9	550	1136.4	351	1487.4	43134.3
P. halepensis	14	Thining	120	–	–	–	–	–	–	–	–	–	–	–
P. halepensis	14	After thining	20	2038	13	6.4	1.3	1.2	2.9	5.1	10.5	3.2	13.7	20332.4
P. halepensis	14	After thining	30	1952	30.1	15.4	3.1	2.7	6.8	11.8	24.4	7.5	32	42887.4
P. halepensis	14	After thining	40	1305	47.1	36.1	6.2	5.3	13.5	23.4	48.4	14.9	63.3	63713.7
P. halepensis	14	After thining	50	1233	64.8	52.6	8.7	7.5	19	33	68.2	21.1	89.2	87174.1
P. halepensis	14	After thining	60	1005	77.5	77.1	12.5	10.7	27.1	47.2	97.5	30.1	127.7	101744.3
P. halepensis	14	After thining	70	862	87.8	101.9	16.2	13.9	35.2	61.4	126.8	39.2	166	113515.7
P. halepensis	14	After thining	80	766	96.1	125.5	19.8	17	43	74.8	154.6	47.8	202.4	123064.5
P. halepensis	14	After thining	90	699	102.9	147.2	23.1	19.8	50.1	87.3	180.4	55.7	236.1	130802.4
P. halepensis	14	After thining	100	650	108.5	166.9	26	22.4	56.5	98.4	203.3	62.8	266.1	137058.5
P. halepensis	14	After thining	110	613	113	184.3	28.6	24.6	62.2	108.2	223.6	69.1	292.7	142244.5
P. halepensis	14	After thining	120	–	–	–	–	–	–	–	–	–	–	–

5.3.3 Carbon sequestration capacity simulations

Using simulated forest growth and values of future biomass and carbon sequestration capacity of selected species (Figure 19, Figure 18, Figure 20, Figure 17) one-time point was selected (~50 years). Tables presented in Figure 21, Figure 22, and Figure 23 show the carbon sequestration for the test sites in Spain. For these areas, two species were proposed for each test site, as indicated in chapter 5.3.1 The Carbon values are given by ML type and by species combination in tones by ha [t/ha] and for all the surface of the ML in kilotonnes by ha [kt/ha]. Here, we observe that the main carbon fixing species in the case of ML1 class is *Pinus nigra* sequestering 157.9 C t/ha whereas *Pinus sylvestris* captures 108.2 C t /ha, *Pinus pinaster* captures 108.1 C t /ha and *Pinus halepensis* captures 88.2 C t /ha. If we observe the amount of carbon fixed for the whole ML area within the Soria test site, planting only *Pinus nigra* would fix 3,963.3 kilotonnes of Carbon. On the other hand planting the whole surface of the ML with *Pinus sylvestris*, 2687.7 kilotonnes of would be fixed.

In Nogueruelas, if we observe the amount of carbon fixed for the whole ML area, planting only *Pinus nigra* would fix 3.2 kilotonnes of Carbon. On the other hand planting the whole surface of the ML with *Pinus sylvestris*, 2.1 kilotonnes of would be fixed.

In Espadan, if we observe the amount of carbon fixed for the whole ML area, planting only *Pinus pinaster* would fix 31.9 kilotonnes of Carbon. On the other hand, planting the whole surface of the ML with *Pinus halepensis*, 38.9 kilotonnes of would be fixed.

Although maximizing the carbon intake of the ML would be better for the plantation of one species, it is encouraged to apply:

- in Soria, a mixture of *Pinus nigra* in 70-80 % and *Pinus sylvestris* in 30-20%,
- in Nogueruelas, a mixture of *Pinus nigra* in 70-80 % and *Pinus sylvestris* in 30-20%,
- in Espadan, a mixture of *Pinus pinaster* in 70-80 % and *Pinus halepensis* in 30-20%,

to enhance biodiversity, resilience against disturbances such as forest fires, extreme weather events, and pests.

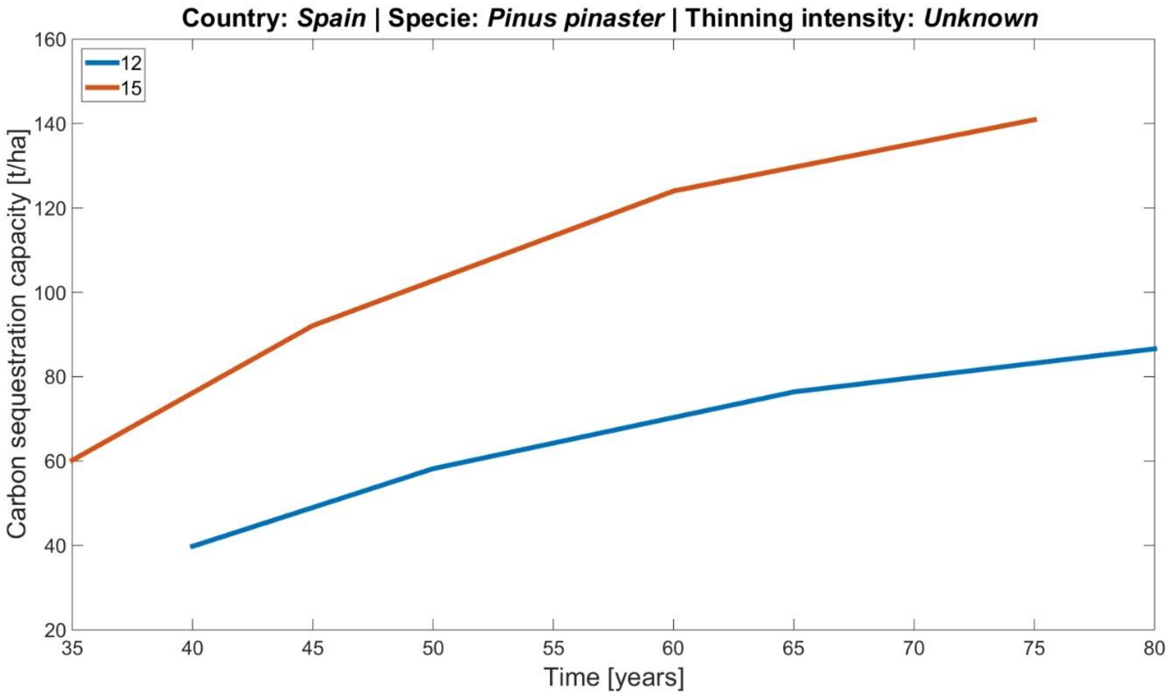

Figure 17. Simulation of carbon sequestration capacity of *Pinus pinaster* in Spain.

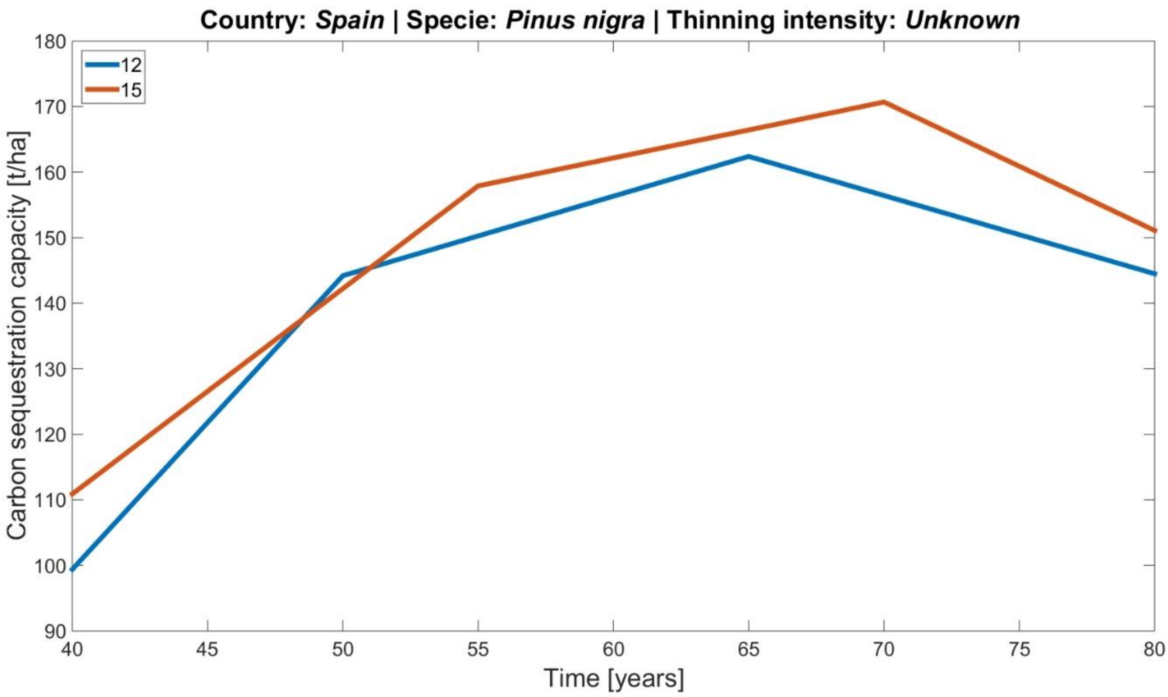

Figure 18. Simulation of carbon sequestration capacity of *Pinus nigra* in Spain.

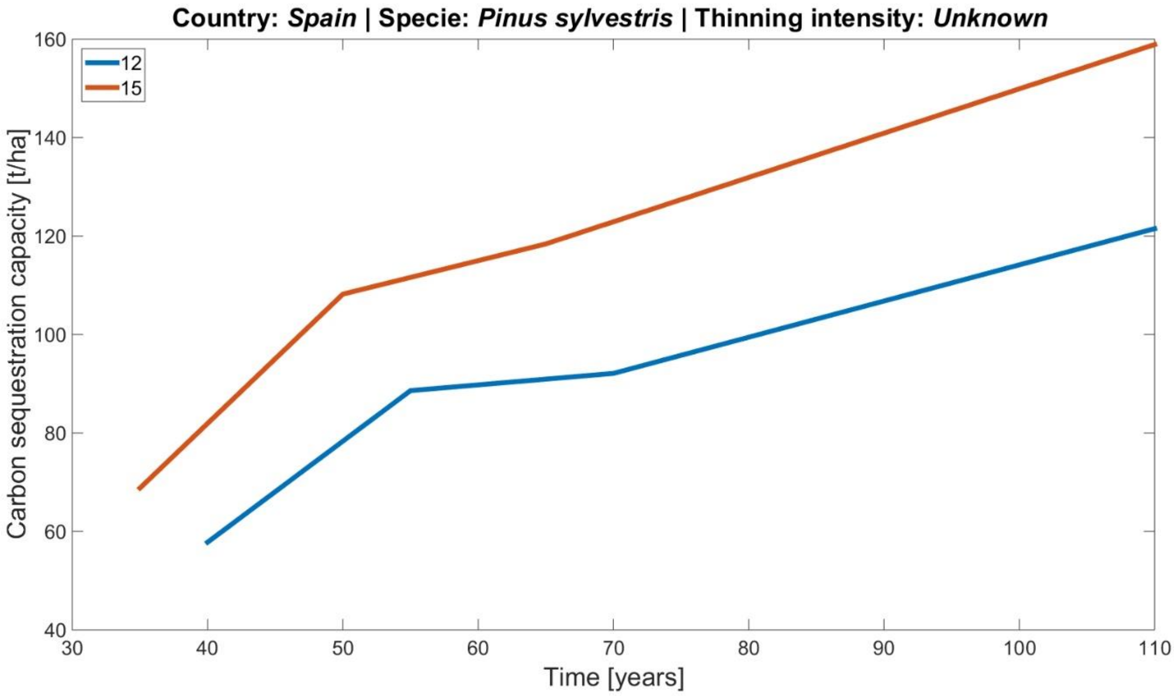

Figure 19. Simulation of carbon sequestration capacity of *Pinus sylvestris* in Spain.

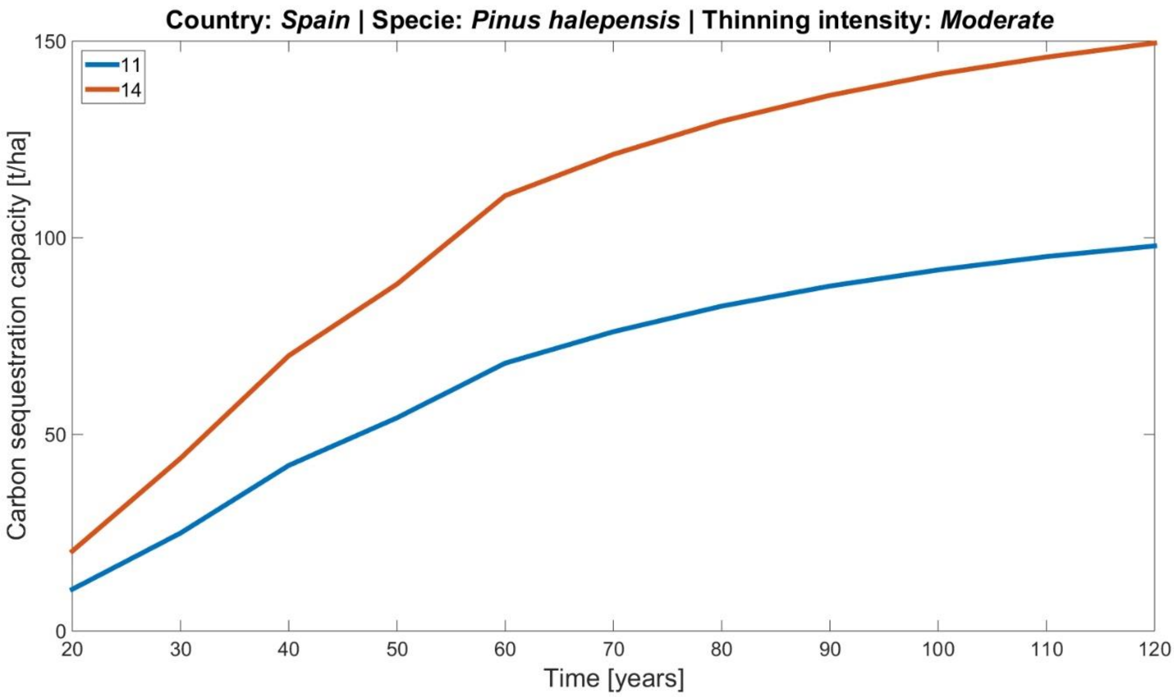

Figure 20. Simulation of carbon sequestration capacity of *Pinus halepensis* in Spain.

Spain | Soria | method C

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	157.9	152.9	148.0	143.0	138.0	133.1	128.1	123.1	118.1	113.2	108.2
	CSC [kt/ML1]	3566.6	3454.4	3342.1	3229.8	3117.6	3005.3	2893.1	2780.8	2668.5	2556.3	2444.0
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	144.2	138.6	133.1	127.5	122.0	116.4	110.8	105.3	99.7	94.2	88.6
	CSC [kt/ML2]	396.7	381.4	366.1	350.8	335.5	320.2	304.9	289.6	274.3	259.0	243.7
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:quality 15 | before thinning | age 50
ML1:Pinus nigra:quality 15 | before thinning | age 55
ML2:Pinus sylvestris:quality 12 | before thinning | age 55
ML2:Pinus nigra:quality 12 | before thinning | age 50

Figure 21. Carbon sequestration capacity of mixed species in “Soria” test site.

Spain | Nogueruelas | method C

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	157.9	152.9	148.0	143.0	138.0	133.1	128.1	123.1	118.1	113.2	108.2
	CSC [kt/ML1]	2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	144.2	138.6	133.1	127.5	122.0	116.4	110.8	105.3	99.7	94.2	88.6
	CSC [kt/ML2]	1.2	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:quality 15 | before thinning | age 50
ML1:Pinus nigra:quality 15 | before thinning | age 55
ML2:Pinus sylvestris:quality 12 | before thinning | age 55
ML2:Pinus nigra:quality 12 | before thinning | age 50

Figure 22. Carbon sequestration capacity of mixed species in “Nogueruelas” test site.

Spain | Espadan | method C

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	108.1	106.1	104.1	102.1	100.1	98.1	96.1	94.2	92.2	90.2	88.2
	CSC [kt/ML1]	36.9	36.2	35.5	34.8	34.2	33.5	32.8	32.1	31.4	30.8	30.1
	Pinus pinaster [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	58.2	57.8	57.4	57.0	56.6	56.2	55.8	55.4	55.0	54.6	54.2
	CSC [kt/ML2]	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8
	Pinus pinaster [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50
ML1:Pinus pinaster:quality 15 | before thinning | mean of age 45 and 60
ML2:Pinus halepensis:quality 12 | before thinning | age 50
ML2:Pinus pinaster:quality 12 | before thinning | age 50

Figure 23. Carbon sequestration capacity of mixed species in “Espadan” test site.

5.4 Greece

The pilot site selected Greece to share the same marginality conditions that the Spanish ones, they are low productivity lands adjacent to natural parks and forest areas. The test sites are located in the Region of Eastern Macedonia and Thrace, and more specifically, the agricultural areas of “Proskynites” and “Xylagani” adjacent to the city of Komotini, Namely, the suburban forest of “Kedrinos Lofos” located in the north and the northeast side of the city of Thessaloniki. The test sites are represented in figure Figure 24.

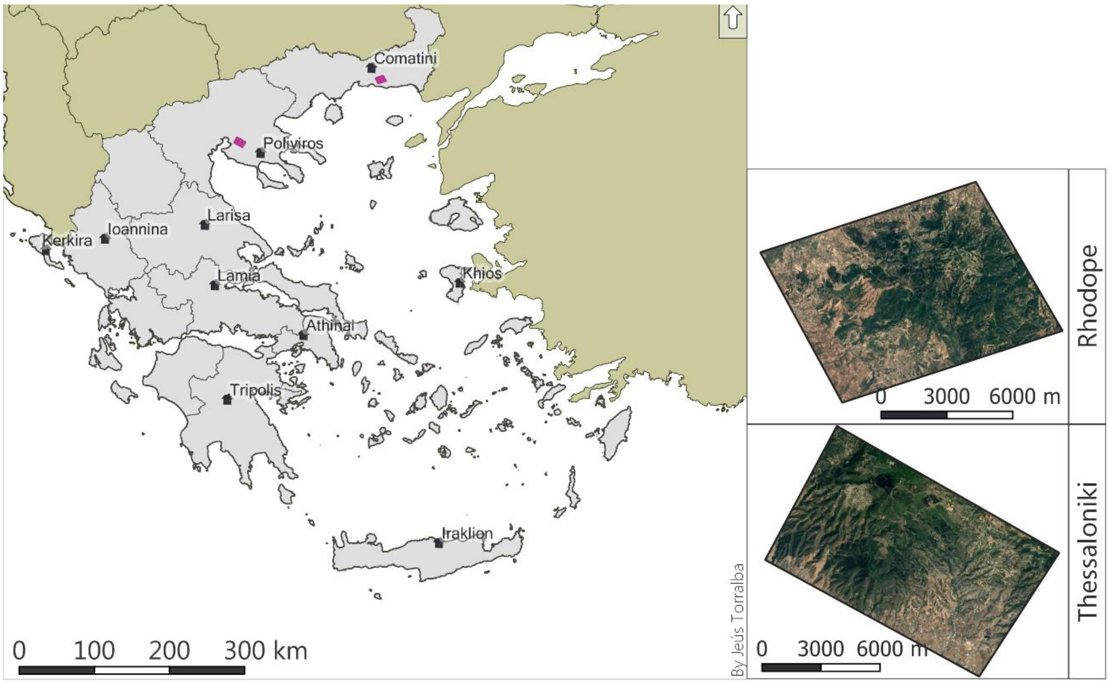

Figure 24. Greece (left) and the pilot site of the afforestation forest of "Rhodope" and "Thessaloniki".

5.4.1 Species selection

The forest inventory shows that coniferous and deciduous trees are equally distributed in the test site (Table 50). The coniferous species are composed of *Pinus brutia* and *Pinus halepensis*, both Mediterranean coniferous species adapted to scarce rainfall regimes, optimal for their implantation in MLs. Although no species composition for broadleaf is retrieved in the forest inventory, after expert consultation with ***MAIL***'s project partner, HOMEOTECH, it was confirmed that the evergreen species present in the Isenli forest was *Quercus frainetto.* Due to the remarkable presence of *Quercus frainetto* in the pilot site area, it was selected as well as a suitable species for the reforestation module.

Table 50. Area distribution for the main species in the Greek test sites.

Species	Plot Count	Presence in plot [%]	Trees / ha	trees [%]
Deciduous broadleaf's	1	2.38	-	-
Evergreen broadleaf's	16	38.10	-	-
Pinus brutia	14	33.33	16,330	53.33
Pinus halepensis	10	23.81	13,940	45.53
Pinus pinaster	1	2.38	350	1.14%
Total	**42**	**100**	**30,620**	**100**

5.4.2 Biomass and carbon estimation by species

The biomass estimations for the species selected for the Greek pilot sites are presented. The carbon values are given for 3 pools the aboveground biomass, below-ground biomass, and the totality of the tree. The biomass estimations for *Pinus halepensis* in Greece were calculated following the values in the yield table for *Pinus halepensis* in Spain. Therefore, the carbon estimations for Pinus halepensis in Greece correspond to the values presented in Table 51.

Table 51. Biomass and Carbon estimation for *Quercus frainetto* for the aboveground and belowground components and total tree.

SI	Age	N	Vol with bark	Vol	Dry weight	Above Ground Biomass (kg/ha)						Below Ground Biomass	Above Ground Carbon (Kg/Ha)						Below Ground Carbon
	year	*trees/ ha*	*m³/ ha*	*m³/ ha*	*kg/ ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+ bark*	*Total ABG*	*kg/ Ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+bark*	*Total ABG*	*Kg/ ha*
IVa	10	8500	24.1	16.6	17834	2116.9	3210.1	2470.0	10037.0	12507.0	17834	4993.5	1058.4	1605.1	1235.0	5018.5	6253.5	8917	2496.8
IVa	12	8260	28.9	20.0	21386	2538.5	3849.5	2962.0	12036.0	14998.0	21386	5988.1	1269.3	1924.7	1481.0	6018.0	7499.0	10693	2994.0
IVa	14	8020	34.0	23.7	25160	2986.5	4528.8	3484.7	14160.0	17644.7	25160	7044.8	1493.2	2264.4	1742.3	7080.0	8822.4	12580	3522.4
IVa	15	7900	36.8	25.7	27232	3232.4	4901.8	3771.6	15326.2	19097.8	27232	7625.0	1616.2	2450.9	1885.8	7663.1	9548.9	13616	3812.5
IVa	16	7760	39.6	27.8	29304	3478.4	5274.7	4058.6	16492.3	20550.9	29304	8205.1	1739.2	2637.4	2029.3	8246.1	10275.4	14652	4102.6
IVa	18	7480	45.7	32.3	33818	4014.2	6087.2	4683.8	19032.8	23716.6	33818	9469.0	2007.1	3043.6	2341.9	9516.4	11858.3	16909	4734.5
IVa	20	7200	51.7	36.7	38258	4541.2	6886.4	5298.7	21531.6	26830.3	38258	10712.2	2270.6	3443.2	2649.4	10765.8	13415.2	19129	5356.1
IVa	22	6840	57.0	40.8	42180	5006.8	7592.4	5841.9	23738.9	29580.8	42180	11810.4	2503.4	3796.2	2921.0	11869.5	14790.4	21090	5905.2
IVa	24	6480	62.0	44.6	45880	5446.0	8258.4	6354.4	25821.3	32175.6	45880	12846.4	2723.0	4129.2	3177.2	12910.6	16087.8	22940	6423.2
IVa	25	6300	64.3	46.3	47582	5648.0	8564.8	6590.1	26779.1	33369.3	47582	13323.0	2824.0	4282.4	3295.1	13389.6	16684.6	23791	6661.5
IVa	26	6020	66.4	48.0	49136	5832.4	8844.5	6805.3	27653.7	34459.1	49136	13758.1	2916.2	4422.2	3402.7	13826.9	17229.5	24568	6879.0
IVa	28	5460	70.5	51.2	52170	6192.6	9390.6	7225.5	29361.3	36586.8	52170	14607.6	3096.3	4695.3	3612.8	14680.6	18293.4	26085	7303.8
IVa	30	4900	74.2	54.4	54908	6517.6	9883.4	7604.8	30902.2	38507.0	54908	15374.2	3258.8	4941.7	3802.4	15451.1	19253.5	27454	7687.1

SI	Age	N	Vol with bark	Vol	Dry weight	Above Ground Biomass (kg/ha)						Below Ground Biomass	Above Ground Carbon (Kg/Ha)						Below Ground Carbon
	year	*trees/ ha*	*m^3/ ha*	*m^3/ ha*	*kg/ ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+ bark*	*Total ABG*	*kg/ Ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+bark*	*Total ABG*	*Kg/ ha*
IVa	32	4420	77.8	57.4	57572	6833.8	10363.0	7973.7	32401.5	40375.2	57572	16120.2	3416.9	5181.5	3986.9	16200.8	20187.6	28786	8060.1
IVa	34	3940	80.9	60.3	59866	7106.1	10775.9	8291.4	33692.6	41984.0	59866	16762.5	3553.0	5387.9	4145.7	16846.3	20992.0	29933	8381.2
IVa	35	3700	82.4	61.7	60976	7237.9	10975.7	8445.2	34317.3	42762.5	60976	17073.3	3618.9	5487.8	4222.6	17158.6	21381.2	30488	8536.6
IVa	36	3640	83.8	62.9	62012	7360.8	11162.2	8588.7	34900.4	43489.0	62012	17363.4	3680.4	5581.1	4294.3	17450.2	21744.5	31006	8681.7
IVa	38	3520	86.4	65.1	63936	7589.2	11508.5	8855.1	35983.2	44838.3	63936	17902.1	3794.6	5754.2	4427.6	17991.6	22419.2	31968	8951.0
IVa	40	3400	88.9	67.2	65786	7808.8	11841.5	9111.4	37024.4	46135.7	65786	18420.1	3904.4	5920.7	4555.7	18512.2	23067.9	32893	9210.0
IVa	42	3400	91.1	68.8	67414	8002.0	12134.5	9336.8	37940.6	47277.4	67414	18875.9	4001.0	6067.3	4668.4	18970.3	23638.7	33707	9438.0
IVa	44	3400	93.2	70.4	68968	8186.5	12414.2	9552.1	38815.2	48367.3	68968	19311.0	4093.3	6207.1	4776.0	19407.6	24183.6	34484	9655.5
IVa	45	3400	94.0	71.2	69560	8256.8	12520.8	9634.1	39148.4	48782.4	69560	19476.8	4128.4	6260.4	4817.0	19574.2	24391.2	34780	9738.4
IVb	10	8700	19.5	13.2	14430	1712.8	2597.4	1998.6	8121.2	10119.8	14430	4040.4	856.4	1298.7	999.3	4060.6	5059.9	7215	2020.2
IVb	12	8460	23.7	16.0	17538	2081.8	3156.8	2429.0	9870.4	12299.4	17538	4910.6	1040.9	1578.4	1214.5	4935.2	6149.7	8769	2455.3
IVb	14	8220	28.4	19.2	21016	2494.6	3782.9	2910.7	11827.8	14738.5	21016	5884.5	1247.3	1891.4	1455.4	5913.9	7369.3	10508	2942.2
IVb	15	8100	30.7	20.9	22718	2696.6	4089.2	3146.4	12785.7	15932.1	22718	6361.0	1348.3	2044.6	1573.2	6392.8	7966.1	11359	3180.5
IVb	16	7960	33.2	22.7	24568	2916.2	4422.2	3402.7	13826.9	17229.5	24568	6879.0	1458.1	2211.1	1701.3	6913.4	8614.8	12284	3439.5
IVb	18	7680	38.4	26.4	28416	3373.0	5114.9	3935.6	15992.5	19928.1	28416	7956.5	1686.5	2557.4	1967.8	7996.3	9964.1	14208	3978.2
IVb	20	7400	43.5	30.1	32190	3821.0	5794.2	4458.3	18116.5	22574.8	32190	9013.2	1910.5	2897.1	2229.2	9058.3	11287.4	16095	4506.6
IVb	22	7040	48.1	33.5	35594	4225.0	6406.9	4929.8	20032.3	24962.1	35594	9966.3	2112.5	3203.5	2464.9	10016.2	12481.0	17797	4983.2
IVb	24	66800	52.6	36.8	38924	4620.3	7006.3	5391.0	21906.4	27297.4	38924	10898.7	2310.1	3503.2	2695.5	10953.2	13648.7	19462	5449.4
IVb	25	6500	54.7	38.4	40478	4804.7	7286.0	5606.2	22781.0	28387.2	40478	11333.8	2402.4	3643.0	2803.1	11390.5	14193.6	20239	5666.9
IVb	26	5940	56.5	39.9	41810	4962.8	7525.8	5790.7	23530.7	29321.4	41810	11706.8	2481.4	3762.9	2895.3	11765.3	14660.7	20905	5853.4
IVb	28	5380	60.2	42.9	44548	5287.8	8018.6	6169.9	25071.6	31241.5	44548	12473.4	2643.9	4009.3	3084.9	12535.8	15620.8	22274	6236.7

SI	Age	N	Vol with bark	Vol	Dry weight	Above Ground Biomass (kg/ha)						Below Ground Biomass	Above Ground Carbon (Kg/Ha)						Below Ground Carbon
	year	*trees/ ha*	*m^3/ ha*	*m^3/ ha*	*kg/ ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+ bark*	*Total ABG*	*kg/ Ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+bark*	*Total ABG*	*Kg/ ha*
IVb	30	5100	63.8	45.6	47212	5604.1	8498.2	6538.9	26570.9	33109.8	47212	13219.4	2802.0	4249.1	3269.4	13285.5	16554.9	23606	6609.7
IVb	32	4620	67.0	48.3	49580	5885.1	8924.4	6866.8	27903.6	34770.5	49580	13882.4	2942.6	4462.2	3433.4	13951.8	17385.2	24790	6941.2
IVb	34	4140	69.8	50.8	51652	6131.1	9297.4	7153.8	29069.7	36223.5	51652	14462.6	3065.5	4648.7	3576.9	14534.9	18111.8	25826	7231.3
IVb	35	3900	71.0	51.9	52540	6236.5	9457.2	7276.8	29569.5	36846.3	52540	14711.2	3118.2	4728.6	3638.4	14784.8	18423.2	26270	7355.6
IVb	36	3840	72.3	53.0	53502	6350.7	9630.4	7410.0	30110.9	37521.0	53502	14980.6	3175.3	4815.2	3705.0	15055.5	18760.5	26751	7490.3
IVb	38	3720	74.9	55.0	55426	6579.1	9976.7	7676.5	31193.8	38870.3	55426	15519.3	3289.5	4988.3	3838.3	15596.9	19435.1	27713	7759.6
IVb	40	3600	77.3	56.9	57202	6789.9	10296.4	7922.5	32193.3	40115.8	57202	16016.6	3394.9	5148.2	3961.2	16096.6	20057.9	28601	8008.3
IVb	42	3600	79.3	58.5	58682	6965.6	10562.8	8127.5	33026.2	41153.7	58682	16431.0	3482.8	5281.4	4063.7	16513.1	20576.8	29341	8215.5
IVb	44	3600	81.0	59.8	59940	7114.9	10789.2	8301.7	33734.2	42035.9	59940	16783.2	3557.4	5394.6	4150.8	16867.1	21018.0	29970	8391.6
IVb	45	3600	81.7	60.3	60458	7176.4	10882.4	8373.4	34025.8	42399.2	60458	16928.2	3588.2	5441.2	4186.7	17012.9	21199.6	30229	8464.1
Va	10	9100	16.0	10.5	11840	1405.4	2131.2	1639.8	6663.6	8303.4	11840	3315.2	702.7	1065.6	819.9	3331.8	4151.7	5920	1657.6
Va	12	8820	19.6	12.8	14504	1721.6	2610.7	2008.8	8162.9	10171.7	14504	4061.1	860.8	1305.4	1004.4	4081.4	5085.8	7252	2030.6
Va	14	8540	23.4	15.4	17316	2055.4	3116.9	2398.3	9745.4	12143.7	17316	4848.5	1027.7	1558.4	1199.1	4872.7	6071.9	8658	2424.2
Va	15	8400	25.6	16.9	18944	2248.7	3409.9	2623.7	10661.7	13285.4	18944	5304.3	1124.3	1705.0	1311.9	5330.8	6642.7	9472	2652.2
Va	16	8262	27.8	18.4	20572	2441.9	3703.0	2849.2	11577.9	14427.1	20572	5760.2	1220.9	1851.5	1424.6	5789.0	7213.6	10286	2880.1
Va	18	7980	32.4	21.6	23976	2846.0	4315.7	3320.7	13493.7	16814.4	23976	6713.3	1423.0	2157.8	1660.3	6746.8	8407.2	11988	3356.6
Va	20	7700	36.6	24.5	27084	3214.9	4875.1	3751.1	15242.9	18994.0	27084	7583.5	1607.4	2437.6	1875.6	7621.4	9497.0	13542	3791.8
Va	22	7380	40.6	27.4	30044	3566.2	5407.9	4161.1	16908.8	21069.9	30044	8412.3	1783.1	2704.0	2080.5	8454.4	10534.9	15022	4206.2
Va	24	7060	44.2	30.0	32708	3882.4	5887.4	4530.1	18408.1	22938.1	32708	9158.2	1941.2	2943.7	2265.0	9204.0	11469.1	16354	4579.1
Va	25	6900	45.8	31.3	33892	4023.0	6100.6	4694.0	19074.4	23768.5	33892	9489.8	2011.5	3050.3	2347.0	9537.2	11884.2	16946	4744.9
Va	26	6700	47.4	32.5	35039	4159.1	6307.0	4852.9	19719.9	24572.9	35039	9810.9	2079.6	3153.5	2426.5	9860.0	12286.4	17520	4905.5

SI	Age	N	Vol with bark	Vol	Dry weight	Above Ground Biomass (kg/ha)						Below Ground Biomass	Above Ground Carbon (Kg/Ha)						Below Ground Carbon
	year	*trees/ ha*	*m^3/ ha*	*m^3/ ha*	*kg/ ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+ bark*	*Total ABG*	*kg/ Ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+bark*	*Total ABG*	*Kg/ ha*
Va	28	6300	50.4	34.8	37296	4427.0	6713.3	5165.5	20990.2	26155.7	37296	10442.9	2213.5	3356.6	2582.7	10495.1	13077.8	18648	5221.4
Va	30	5900	53.2	37.0	39368	4673.0	7086.2	5452.5	22156.3	27608.8	39368	11023.0	2336.5	3543.1	2726.2	11078.2	13804.4	19684	5511.5
Va	32	5420	55.8	39.0	41292	4901.4	7432.6	5718.9	23239.1	28958.1	41292	11561.8	2450.7	3716.3	2859.5	11619.6	14479.0	20646	5780.9
Va	34	4940	58.0	40.9	42920	5094.6	7725.6	5944.4	24155.4	30099.8	42920	12017.6	2547.3	3862.8	2972.2	12077.7	15049.9	21460	6008.8
Va	35	4700	59.1	41.8	43734	5191.2	7872.1	6057.2	24613.5	30670.7	43734	12245.5	2595.6	3936.1	3028.6	12306.7	15335.3	21867	6122.8
Va	36	4620	60.1	42.6	44474	5279.1	8005.3	6159.6	25030.0	31189.6	44474	12452.7	2639.5	4002.7	3079.8	12515.0	15594.8	22237	6226.4
Va	38	4460	62.1	44.1	45954	5454.7	8271.7	6364.6	25862.9	32227.5	45954	12867.1	2727.4	4135.9	3182.3	12931.5	16113.8	22977	6433.6
Va	40	4300	63.9	45.5	47286	5612.8	8511.5	6549.1	26612.6	33161.7	47286	13240.1	2806.4	4255.7	3274.6	13306.3	16580.8	23643	6620.0
Va	42	4300	65.7	46.8	48618	5771.0	8751.2	6733.6	27362.2	34095.8	48618	13613.0	2885.5	4375.6	3366.8	13681.1	17047.9	24309	6806.5
Va	44	4300	67.0	47.9	49580	5885.1	8924.4	6866.8	27903.6	34770.5	49580	13882.4	2942.6	4462.2	3433.4	13951.8	17385.2	24790	6941.2
Va	45	4300	67.7	48.4	50098	5946.6	9017.6	6938.6	28195.2	35133.7	50098	14027.4	2973.3	4508.8	3469.3	14097.6	17566.9	25049	7013.7
Vb	10	9300	12.1	7.7	8954	1062.8	1611.7	1240.1	5039.3	6279.4	8954	2507.1	531.4	805.9	620.1	2519.7	3139.7	4477	1253.6
Vb	12	9020	15.0	9.6	11100	1317.6	1998.0	1537.4	6247.1	7784.4	11100	3108.0	658.8	999.0	768.7	3123.5	3892.2	5550	1554.0
Vb	14	8740	18.3	11.8	13542	1607.4	2437.6	1875.6	7621.4	9497.0	13542	3791.8	803.7	1218.8	937.8	3810.7	4748.5	6771	1895.9
Vb	15	8600	20.0	12.9	14800	1756.8	2664.0	2049.8	8329.4	10379.2	14800	4144.0	878.4	1332.0	1024.9	4164.7	5189.6	7400	2072.0
Vb	16	8460	21.7	14.0	16058	1906.1	2890.4	2224.0	9037.4	11261.5	16058	4496.2	953.0	1445.2	1112.0	4518.7	5630.7	8029	2248.1
Vb	18	8180	25.4	16.5	18796	2231.1	3383.3	2603.2	10578.4	13181.6	18796	5262.9	1115.5	1691.6	1301.6	5289.2	6590.8	9398	2631.4
Vb	20	7900	18.8	18.8	13912	1651.4	2504.2	1926.8	7829.7	9756.5	13912	3895.4	825.7	1252.1	963.4	3914.8	4878.2	6956	1947.7
Vb	22	7580	32.0	20.9	23680	2810.8	4262.4	3279.7	13327.1	16606.8	23680	6630.4	1405.4	2131.2	1639.8	6663.6	8303.4	11840	3315.2
Vb	24	7260	35.0	23.0	25900	3074.3	4662.0	3587.2	14576.5	18163.7	25900	7252.0	1537.2	2331.0	1793.6	7288.3	9081.8	12950	3626.0
Vb	25	7100	36.4	23.9	26936	3197.3	4848.5	3730.6	15159.6	18890.2	26936	7542.1	1598.7	2424.2	1865.3	7579.8	9445.1	13468	3771.0

SI	Age	N	Vol with bark	Vol	Dry weight	Above Ground Biomass (kg/ha)						Below Ground Biomass	Above Ground Carbon (Kg/Ha)						Below Ground Carbon
	year	*trees/ ha*	*m^3/ ha*	*m^3/ ha*	*kg/ ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+ bark*	*Total ABG*	*kg/ Ha*	*Foliage*	*Branch*	*Bark*	*Stem*	*Stem+bark*	*Total ABG*	*Kg/ ha*
Vb	26	6900	37.6	24.8	27824	3302.7	5008.3	3853.6	15659.3	19513.0	27824	7790.7	1651.4	2504.2	1926.8	7829.7	9756.5	13912	3895.4
Vb	28	6500	39.9	26.6	29526	3504.7	5314.7	4089.4	16617.2	20706.6	29526	8267.3	1752.4	2657.3	2044.7	8308.6	10353.3	14763	4133.6
Vb	30	6100	42.1	28.2	31154	3698.0	5607.7	4314.8	17533.5	21848.3	31154	8723.1	1849.0	2803.9	2157.4	8766.7	10924.2	15577	4361.6
Vb	32	5620	44.0	29.8	32560	3864.9	5860.8	4509.6	18324.8	22834.3	32560	9116.8	1932.4	2930.4	2254.8	9162.4	11417.2	16280	4558.4
Vb	34	5140	45.6	31.3	33744	4005.4	6073.9	4673.5	18991.1	23664.7	33744	9448.3	2002.7	3037.0	2336.8	9495.6	11832.3	16872	4724.2
Vb	35	4900	46.4	32.0	34336	4075.7	6180.5	4755.5	19324.3	24079.8	34336	9614.1	2037.8	3090.2	2377.8	9662.2	12039.9	17168	4807.0
Vb	36	4820	47.3	32.6	35002	4154.7	6300.4	4847.8	19699.1	24546.9	35002	9800.6	2077.4	3150.2	2423.9	9849.6	12273.5	17501	4900.3
Vb	38	4620	48.8	33.8	36112	4286.5	6500.2	5001.5	20323.8	25325.3	36112	10111.4	2143.2	3250.1	2500.8	10161.9	12662.7	18056	5055.7
Vb	40	4500	50.5	35.0	37370	4435.8	6726.6	5175.7	21031.8	26207.6	37370	10463.6	2217.9	3363.3	2587.9	10515.9	13103.8	18685	5231.8
Vb	42	4500	52.0	36.1	38480	4567.6	6926.4	5329.5	21656.5	26986.0	38480	10774.4	2283.8	3463.2	2664.7	10828.3	13493.0	19240	5387.2
Vb	44	4500	53.5	37.2	39590	4699.3	7126.2	5483.2	22281.3	27764.5	39590	11085.2	2349.7	3563.1	2741.6	11140.6	13882.2	19795	5542.6
Vb	45	4500	54.2	37.7	40108	4760.8	7219.4	5555.0	22572.8	28127.7	40108	11230.2	2380.4	3609.7	2777.5	11286.4	14063.9	20054	5615.1

5.4.3 Carbon sequestration capacity simulations

Using simulated forest growth and values of future biomass and carbon sequestration capacity of selected species (Figure 20, Figure 25) one-time point was selected (45 years). Tables presented in Figure 26 and Figure 27 show the carbon sequestration for the test sites in Greece. For these areas, two species were proposed as indicated in chapter 5.4.1 The Carbon values are given by ML type and by species combination in tones by ha [t/ha] and for all the surface of the ML in kilotonnes by ha [kt/ha]. Here, we observe that the main carbon fixing species is *Pinus halepensis* sequestering 88.2 C t/ha whereas *Quercus frainetto* captures 72.0 C t /ha in the case of ML1 class. If we observe the amount of carbon fixed for the whole ML area, planting only *Pinus halepensis* would fix 228.7 kilotonnes of Carbon in Rhodope and 396.2 kilotonnes of Carbon in the Thessaloniki test site. On the other hand planting the whole surface of the ML with *Quercus frainetto*, 86.7 kilotonnes of Carbon in Rhodope, and 145.1 kilotonnes of Carbon in Thessaloniki would be fixed.

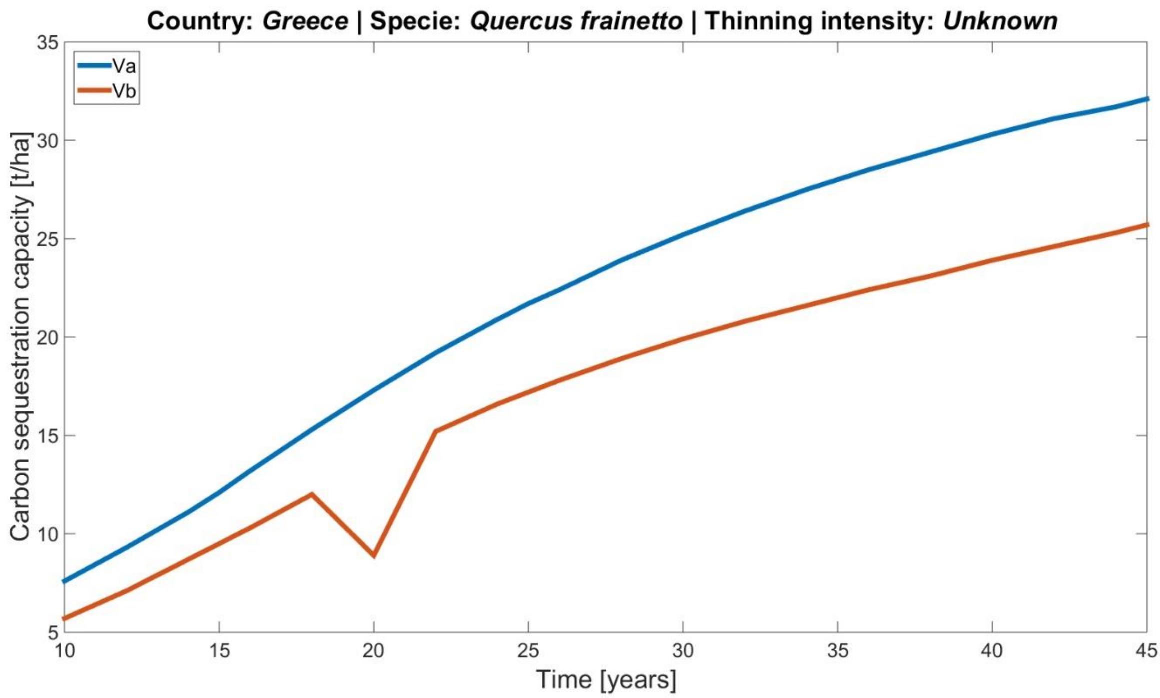

Figure 25. Simulation of carbon sequestration capacity of *Quercus frainetto* in Greece.

Greece | Rhodope | method C

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	32.1	37.7	43.3	48.9	54.5	60.2	65.8	71.4	77.0	82.6	88.2
	CSC [kt/ML1]	72.0	84.5	97.1	109.7	122.3	134.8	147.4	160.0	172.6	185.1	197.7
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	25.7	28.6	31.4	34.3	37.1	40.0	42.8	45.6	48.5	51.4	54.2
	CSC [kt/ML2]	14.7	16.3	18.0	19.6	21.2	22.9	24.5	26.1	27.7	29.4	31.0
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50 | values from Spain
ML1:Quercus species:class Va | before thinning | age 45
ML2:Pinus halepensis:quality 12 | before thinning | age 50 | values from Spain
ML2:Quercus species:class Vb | before thinning | age 45

Figure 26. Carbon sequestration capacity of mixed species in "Rhodope" test site.

Greece | Thessaloniki | method C

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	32.1	37.7	43.3	48.9	54.5	60.2	65.8	71.4	77.0	82.6	88.2
	CSC [kt/ML1]	141.0	165.6	190.3	214.9	239.5	264.2	288.8	313.4	338.1	362.7	387.4
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	25.7	28.6	31.4	34.3	37.1	40.0	42.8	45.6	48.5	51.4	54.2
	CSC [kt/ML2]	4.1	4.6	5.1	5.5	6.0	6.5	6.9	7.4	7.8	8.3	8.8
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50 | values from Spain
ML1:Quercus species:class Va | before thinning | age 45
ML2:Pinus halepensis:quality 12 | before thinning | age 50 | values from Spain
ML2:Quercus species:class Vb | before thinning | age 45

Figure 27. Carbon sequestration capacity of mixed species in "Thessaloniki" test site.

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ANNEX I: TABLES OF FIGURES

ANNEX II: LIST OF TABLES

ANNEX III: CARBON ESTIMATION FOR THE PILOT SITE: RESULTS

Carbon sequestration capacity for test sites estimated using method A.

Germany

Germany | Welzow | method A

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	148.3	144.4	140.6	136.7	132.9	129.0	125.1	121.3	117.4	113.6	109.7
	CSC [kt/ML1]	4.0	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	153.8	148.2	142.5	136.9	131.2	125.6	120.0	114.3	108.7	103.0	97.4
	CSC [kt/ML2]	239.1	230.4	221.6	212.8	204.1	195.3	186.5	177.7	169.0	160.2	151.4
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:Mittelhöhenbonität 20 | after thinning + thinning | low thinning intensity | age 50
ML1:Picea abies:IV.Ertrags | after thinning | medium intensity | no other data available | age 50
ML2:Pinus sylvestris:Mittelhöhenbonität 18 | after thinning + thinning | low thinning intensity | age 50
ML2:Picea abies:V.Ertrags | after thinning | medium intensity | no other data available | age 50

Germany | Nochte | method A

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	148.3	144.4	140.6	136.7	132.9	129.0	125.1	121.3	117.4	113.6	109.7
	CSC [kt/ML1]	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	153.8	148.2	142.5	136.9	131.2	125.6	120.0	114.3	108.7	103.0	97.4
	CSC [kt/ML2]	311.2	299.8	288.4	277.0	265.5	254.1	242.7	231.3	219.9	208.5	197.1
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:Mittelhöhenbonität 20 | after thinning + thinning | low thinning intensity | age 50
ML1:Picea abies:IV.Ertrags | after thinning | medium intensity | no other data available | age 50
ML2:Pinus sylvestris:Mittelhöhenbonität 18 | after thinning + thinning | low thinning intensity | age 50
ML2:Picea abies:V.Ertrags | after thinning | medium intensity | no other data available | age 50

Poland

Poland | Staszów | method A

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	63.6	62.5	61.5	60.4	59.3	58.3	57.2	56.1	55.0	54.0	52.9
	CSC [kt/ML1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	45.6	45.1	44.7	44.2	43.7	43.3	42.8	42.4	41.9	41.4	41.0
	CSC [kt/ML2]	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:class IV weak treatment | before thinning | age 50
ML1:Quercus species:class III and weak treatment | before thinning | age 50
ML2:Pinus sylvestris:class V weak treatment | before thinning | age 50
ML2:Quercus species:class IV and weak treatment | before thinning | age 50

Spain

Spain | Soria | method A

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	157.9	152.9	148.0	143.0	138.0	133.1	128.1	123.1	118.1	113.2	108.2
	CSC [kt/ML1]	570.3	552.3	534.4	516.4	498.5	480.5	462.6	444.6	426.7	408.7	390.8
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	144.2	138.6	133.1	127.5	122.0	116.4	110.8	105.3	99.7	94.2	88.6
	CSC [kt/ML2]	2767.8	2661.1	2554.4	2447.6	2340.9	2234.2	2127.5	2020.8	1914.0	1807.3	1700.6
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:quality 15 | before thinning | age 50
ML1:Pinus nigra:quality 15 | before thinning | age 55
ML2:Pinus sylvestris:quality 12 | before thinning | age 55
ML2:Pinus nigra:quality 12 | before thinning | age 50

Spain | Noguerueles | method A

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	157.9	152.9	148.0	143.0	138.0	133.1	128.1	123.1	118.1	113.2	108.2
	CSC [kt/ML1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	144.2	138.6	133.1	127.5	122.0	116.4	110.8	105.3	99.7	94.2	88.6
	CSC [kt/ML2]	1.8	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.1
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:quality 15 | before thinning | age 50
ML1:Pinus nigra:quality 15 | before thinning | age 55
ML2:Pinus sylvestris:quality 12 | before thinning | age 55
ML2:Pinus nigra:quality 12 | before thinning | age 50

Spain | Espadan | method A

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	108.1	106.1	104.1	102.1	100.1	98.1	96.1	94.2	92.2	90.2	88.2
	CSC [kt/ML1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pinus pinaster [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	58.2	57.8	57.4	57.0	56.6	56.2	55.8	55.4	55.0	54.6	54.2
	CSC [kt/ML2]	19.9	19.8	19.6	19.5	19.3	19.2	19.1	18.9	18.8	18.7	18.5
	Pinus pinaster [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50
ML1:Pinus pinaster:quality 15 | before thinning | mean of age 45 and 60
ML2:Pinus halepensis:quality 12 | before thinning | age 50
ML2:Pinus pinaster:quality 12 | before thinning | age 50

Greece

Greece | Rhodope | method A

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	32.1	37.7	43.3	48.9	54.5	60.2	65.8	71.4	77.0	82.6	88.2
	CSC [kt/ML1]	18.3	21.5	24.6	27.8	31.0	34.2	37.4	40.6	43.8	47.0	50.2
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	25.7	28.6	31.4	34.3	37.1	40.0	42.8	45.6	48.5	51.4	54.2
	CSC [kt/ML2]	46.5	51.7	56.8	62.0	67.1	72.3	77.5	82.6	87.8	92.9	98.1
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50 | values from Spain
ML1:Quercus species:class Va | before thinning | age 45
ML2:Pinus halepensis:quality 12 | before thinning | age 50 | values from Spain
ML2:Quercus species:class Vb | before thinning | age 45

Greece | Thessaloniki | method A

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	32.1	37.7	43.3	48.9	54.5	60.2	65.8	71.4	77.0	82.6	88.2
	CSC [kt/ML1]	83.4	97.9	112.5	127.1	141.6	156.2	170.8	185.3	199.9	214.5	229.0
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	25.7	28.6	31.4	34.3	37.1	40.0	42.8	45.6	48.5	51.4	54.2
	CSC [kt/ML2]	48.5	53.9	59.3	64.6	70.0	75.4	80.8	86.2	91.5	96.9	102.3
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50 | values from Spain
ML1:Quercus species:class Va | before thinning | age 45
ML2:Pinus halepensis:quality 12 | before thinning | age 50 | values from Spain
ML2:Quercus species:class Vb | before thinning | age 45

Carbon sequestration capacity for test sites estimated using method B.

Germany

Germany | Welzow | method B

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	148.3	144.4	140.6	136.7	132.9	129.0	125.1	121.3	117.4	113.6	109.7
	CSC [kt/ML1]	162.5	158.2	154.0	149.8	145.5	141.3	137.1	132.9	128.6	124.4	120.2
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	153.8	148.2	142.5	136.9	131.2	125.6	120.0	114.3	108.7	103.0	97.4
	CSC [kt/ML2]	836.3	805.6	775.0	744.3	713.6	683.0	652.3	621.6	591.0	560.3	529.6
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:Mittelhöhenbonität 20 | after thinning + thinning | low thinning intensity | age 50
ML1:Picea abies:IV.Ertrags | after thinning | medium intensity | no other data available | age 50
ML2:Pinus sylvestris:Mittelhöhenbonität 18 | after thinning + thinning | low thinning intensity | age 50
ML2:Picea abies:V.Ertrags | after thinning | medium intensity | no other data available | age 50

Germany | Nochte | method B

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	148.3	144.4	140.6	136.7	132.9	129.0	125.1	121.3	117.4	113.6	109.7
	CSC [kt/ML1]	186.2	181.3	176.5	171.7	166.8	162.0	157.1	152.3	147.4	142.6	137.7
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	153.8	148.2	142.5	136.9	131.2	125.6	120.0	114.3	108.7	103.0	97.4
	CSC [kt/ML2]	2751.7	2650.8	2549.9	2449.0	2348.1	2247.2	2146.3	2045.4	1944.5	1843.5	1742.6
	Picea abies [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:Mittelhöhenbonität 20 | after thinning + thinning | low thinning intensity | age 50
ML1:Picea abies:IV.Ertrags | after thinning | medium intensity | no other data available | age 50
ML2:Pinus sylvestris:Mittelhöhenbonität 18 | after thinning + thinning | low thinning intensity | age 50
ML2:Picea abies:V.Ertrags | after thinning | medium intensity | no other data available | age 50

Poland

Poland | Staszów | method B

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	63.6	62.5	61.5	60.4	59.3	58.3	57.2	56.1	55.0	54.0	52.9
	CSC [kt/ML1]	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	45.6	45.1	44.7	44.2	43.7	43.3	42.8	42.4	41.9	41.4	41.0
	CSC [kt/ML2]	159.0	157.4	155.8	154.2	152.6	150.9	149.3	147.7	146.1	144.5	142.9
	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:class IV weak treatment | before thinning | age 50
ML1:Quercus species:class III and weak treatment | before thinning | age 50
ML2:Pinus sylvestris:class V weak treatment | before thinning | age 50
ML2:Quercus species:class IV and weak treatment | before thinning | age 50

Spain

Spain | Soria | method B

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	157.9	152.9	148.0	143.0	138.0	133.1	128.1	123.1	118.1	113.2	108.2
	CSC [kt/ML1]	3216.0	3114.8	3013.5	2912.3	2811.1	2709.9	2608.6	2507.4	2406.2	2305.0	2203.7
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	144.2	138.6	133.1	127.5	122.0	116.4	110.8	105.3	99.7	94.2	88.6
	CSC [kt/ML2]	732.9	704.6	676.3	648.1	619.8	591.6	563.3	535.1	506.8	478.5	450.3
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:quality 15 | before thinning | age 50
ML1:Pinus nigra:quality 15 | before thinning | age 55
ML2:Pinus sylvestris:quality 12 | before thinning | age 55
ML2:Pinus nigra:quality 12 | before thinning | age 50

Spain | Nogueruelas | method B

ML 1	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	157.9	152.9	148.0	143.0	138.0	133.1	128.1	123.1	118.1	113.2	108.2
	CSC [kt/ML1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus sylvestris [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	144.2	138.6	133.1	127.5	122.0	116.4	110.8	105.3	99.7	94.2	88.6
	CSC [kt/ML2]	3.0	2.9	2.8	2.7	2.6	2.4	2.3	2.2	2.1	2.0	1.9
	Pinus nigra [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus sylvestris:quality 15 | before thinning | age 50
ML1:Pinus nigra:quality 15 | before thinning | age 55
ML2:Pinus sylvestris:quality 12 | before thinning | age 55
ML2:Pinus nigra:quality 12 | before thinning | age 50

Spain | Espadan | method B

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	108.1	106.1	104.1	102.1	100.1	98.1	96.1	94.2	92.2	90.2	88.2
	CSC [kt/ML1]	11.1	10.9	10.7	10.5	10.3	10.1	9.9	9.7	9.5	9.3	9.1
	Pinus pinaster [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
	CSC [t/ha]	58.2	57.8	57.4	57.0	56.6	56.2	55.8	55.4	55.0	54.6	54.2
	CSC [kt/ML2]	15.8	15.7	15.6	15.5	15.4	15.3	15.2	15.1	15.0	14.9	14.7
	Pinus pinaster [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50
ML1:Pinus pinaster:quality 15 | before thinning | mean of age 45 and 60
ML2:Pinus halepensis:quality 12 | before thinning | age 50
ML2:Pinus pinaster:quality 12 | before thinning | age 50

Greece

Greece | Rhodope | method B

		0	10	20	30	40	50	60	70	80	90	100
ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
ML 1	CSC [t/ha]	32.1	37.7	43.3	48.9	54.5	60.2	65.8	71.4	77.0	82.6	88.2
ML 1	CSC [kt/ML1]	65.0	76.4	87.7	99.1	110.4	121.8	133.1	144.5	155.9	167.2	178.6
ML 1	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
ML 2	CSC [t/ha]	25.7	28.6	31.4	34.3	37.1	40.0	42.8	45.6	48.5	51.4	54.2
ML 2	CSC [kt/ML2]	20.3	22.5	24.8	27.0	29.3	31.5	33.8	36.0	38.3	40.5	42.7
ML 2	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50 | values from Spain
ML1:Quercus species:class Va | before thinning | age 45
ML2:Pinus halepensis:quality 12 | before thinning | age 50 | values from Spain
ML2:Quercus species:class Vb | before thinning | age 45

Greece | Thessaloniki | method B

ML 1	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
ML 1	CSC [t/ha]	32.1	37.7	43.3	48.9	54.5	60.2	65.8	71.4	77.0	82.6	88.2
ML 1	CSC [kt/ML1]	140.5	165.1	189.6	214.2	238.7	263.3	287.9	312.4	337.0	361.5	386.1
ML 1	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0
ML 2	Pinus halepensis [%]	0	10	20	30	40	50	60	70	80	90	100
ML 2	CSC [t/ha]	25.7	28.6	31.4	34.3	37.1	40.0	42.8	45.6	48.5	51.4	54.2
ML 2	CSC [kt/ML2]	6.3	7.0	7.6	8.3	9.0	9.7	10.4	11.1	11.8	12.5	13.2
ML 2	Quercus species [%]	100	90	80	70	60	50	40	30	20	10	0

ML1:Pinus halepensis:quality 15 | before thinning | age 50 | values from Spain
ML1:Quercus species:class Va | before thinning | age 45
ML2:Pinus halepensis:quality 12 | before thinning | age 50 | values from Spain
ML2:Quercus species:class Vb | before thinning | age 45