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Guidance on biomass estimation at age 40 years since planting

Technical Annex

Action: D.1

Beneficiary responsible for deliverable: IFER – Monitoring and Mapping Solutions

Authors: Emil Cienciala, Jorge Palmero Barrachina, Jan Albert, Petr Blažek, Tiago Santana

Summary

Introduction **3**

Methodology **4**

- Biogeographic regions 4
- Groups of species 5
- Tree biomass functions 5
- Yield tables 7
- Estimation procedure for tree level biomass 9
- From tree level to plantation level 9
- Mortality considerations 10
- From dry weight biomass to C, and from C to CO2 equivalent 12

Results **13**

- Tree level 13
- Stand (plantation) level 16
- Survival rates in timber plantations 17

Discussion **18**

- Biomass estimates – issues to consider 18

Conclusions **21**

References **22**

Annex I **1**

- Groups of species 2

Annex II **1**

Biomass estimation example **2**

Introduction

Life Terra Foundation intends to plant 500 million trees by 2025. Trees, forest stands, and forest ecosystems provide several essential benefits to mankind and nature. Carbon sequestration is one of these benefits. One big challenge for Life Terra Foundation is to transparently quantify the carbon sequestered in tree biomass by their plantations to monitor the progress not only in terms of trees planted, but also in terms of CO_2 offset that these trees represent. IFER designed a guiding procedure to assess carbon storage for trees and stands to be used in Life Terra Foundation. To make the estimation feasible, the procedure was designed with respect to the actual input information available, providing information on uncertainty considerations with respect to the expected mortality and options to increase accuracy using locally available biomass equations and sampling programs such as sample-based national forest inventories. The estimation procedure is designed to be applicable at both tree and stand level.

This document describes the estimation procedure of the expected tree and/or stand living biomass of the Life Terra plantations at age 40 years. It is based on the previous general guidance (Cienciala et al., 2021) for biomass estimation.

Methodology

The estimation of total tree living biomass of the Life Terra plantations that is expected at age of 40 years is specific to biogeographic regions, tree species and/or tree species groups and types. The estimation uses the local allometric equations, yield tables and, national sample-based forest inventories (NFI) and Greenhouse gas (GHG) emission inventories to the most practicable extent as described below.

Countries & Biogeographic regions

Tree growth performance and species composition is primarily specific with respect to each country with its specific climate conditions and landscape topography. Each plantation will be primarily classified by the country where they are located.

In case there is no country specific data available, the plantings will be also classified by the biogeographic region where they are located. These are shown together with the locations of the Life Terra plantations in Fig. 1.

Fig. 1: Biogeographic regions in Europe and locations of Life Terra plantations as of July 2022. Source of biogeographic regions: [European Environment Agency (EEA)]

So far, Life Terra has planted trees in four biogeographic regions: Atlantic, Continental, Mediterranean and Alpine. For each biogeographic region, data for a specific representative country, inside the respective biogeographic region, will be used.

Groups of species

Life Terra Foundation has planted more than 250 tree species (as of July 2022) since the beginning of the project. These species are available in the Life Terra database. The biomass estimation procedure requires species-specific information on allometry and growth performance, which is generally not available for all species. Therefore, apart from species-specific estimation, species grouping was used based on species genus and similarity in terms of tree shape and wood density. The following group types are used:

- Broadleaves
- Conifers
- Shrubs

The use of group types means using an average biomass estimate for all available tree species for a given biogeographic region, country, and productivity class (site index) as described below. Species grouping concerns both broadleaved and coniferous trees.

As for shrubs, in absence of applicable literature, these were considered to reach an amount of biomass equal to that of *Frangula alnus*.

Tree biomass functions

Tree biomass functions are the fundamental tools to estimate tree biomass from measurable dimensions. As was described in the previous general guidance for biomass estimation (Cienciala et al., 2021), there is a wealth of published approaches applicable to larger trees (diameter at breast height (DBH) > 5 cm, age >15 years) that contain dimensions of merchantable biomass. These approaches may either use tree or stand volume and convert it to biomass or use specific biomass functions suited for particular tree species. These functions usually rely on DBH, tree height and often also use some complementary explanatory (input) variables.

Allometric equations as tree biomass functions

Allometric equations are used to estimate tree and forest biomass. The independent variables of these equations are most commonly DBH and/or tree height, which are dimensions that are easy to measure for many trees. Usually, allometric equations take the form of power function (Somogyi et al., 2007; Vonderach et al., 2018; Wirth et al., 2004).

$$b_i = \beta_0 + \beta_1 x_1^{\beta_2} + \beta_3 x_2^{\beta_4} \quad (1)$$

where β are the equation parameters, b the biomass of tree component (stem, branches, leaves, roots, etc.) i and x_1 and x_2 the independent variables (DBH and tree height).

It is important to recognize that most of the data provided on tree biomass may include only aboveground biomass (AGB) components. Since Life Terra is concerned with carbon and CO_2 equivalents stored in the entire tree, one should estimate total tree biomass (TB), which includes also the below-ground component (BGB). It holds that AGB + BGB = TB.

When the belowground biomass component was missing in the allometric equations, suitable expansion factors from table 4.4 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) were used.

The leaf component (leaves) is commonly calculated for the winter stage, which implies that broadleaves are counted without leaves (forming a part of litter) while the biomass estimates of conifers include needles.

The set of available biomass functions used to estimate tree biomass is shown in Table 1. So far, biomass outputs from six tree species of the Alpine biogeographic region, 14 tree species of the Atlantic, 12 tree species of the Continental and six tree species of the Mediterranean have been analyzed (Table 2).

Table 1: Set of biomass functions by biogeographic region, author, and tree species

Bioregion	Author	Tree species
Alpine	Gasparini et al., 2006	*Abies alba*
Alpine	Gasparini et al., 2006	*Fagus sylvatica*
Alpine	Gasparini et al., 2006	*Larix decidua*
Alpine	Gasparini et al., 2006	*Picea abies*
Alpine	Gasparini et al., 2006	*Pinus cembra*
Alpine	Gasparini et al., 2006	*Pinus sylvestris*
Atlantic	Fortier et al., 2017	*Populus cul.*
Atlantic	Liepiņš et al., 2021	*Alnus glutinosa*
Atlantic	Marklund, 1989	*Betula pendula*
Atlantic	Rock, 2007	*Populus tremula*
Atlantic	Vonderach et al., 2018	*Acer pseudoplatanus*
Atlantic	Vonderach et al., 2018	*Fagus sylvatica*
Atlantic	Vonderach et al., 2018	*Fraxinus excelsior*
Atlantic	Vonderach et al., 2018	*Picea abies*
Atlantic	Vonderach et al., 2018	*Pinus sylvestris*
Atlantic	Vonderach et al., 2018	*Pseudotsuga menziesii*
Atlantic	Vonderach et al., 2018	*Quercus robur*
Continental	Bronisz et al., 2016	*Betula verrucosa*

Bioregion	Author	Tree species
Continental	Cienciala et al., 2006	*Pinus sylvestris*
Continental	Cienciala et al., 2008	*Quercus robur*
Continental	Jagodziński et al., 2018	*Larix decidua*
Continental	Suchomel et al., 2012	*Carpinus betulus*
Continental	Vonderach et al., 2018	*Abies alba*
Continental	Wirth et al., 2004	*Picea abies*
Continental	Wutzler et al., 2008	*Fagus sylvatica*
Continental	Liepiņš et al., 2021	*Alnus glutinosa*
Continental	Vonderach et al., 2018	*Fraxinus excelsior*
Continental	Fortier et al., 2017	*Populus cul.*
Continental	Vonderach et al., 2018	*Pseudotsuga menziessi*
Mediterranean	Canadell et al., 1988	*Quercus ilex*
Mediterranean	Ruiz-Peinado Gertrudix, 2013	*Pinus halepensis*
Mediterranean	Ruiz-Peinado Gertrudix, 2013	*Pinus nigra*
Mediterranean	Ruiz-Peinado Gertrudix, 2013	*Pinus pinaster*
Mediterranean	Ruiz-Peinado Gertrudix, 2013	*Pinus pinea*
Mediterranean	Ruiz-Peinado Gertrudix, 2013	*Pinus sylvestris*
Mediterranean	Ruiz-Peinado Gertrudix, 2013	*Quercus ilex*

Biogeoregion = biogeographic region

Allometric equations for shrubs

Hamelin et al. (2015) described the aboveground biomass of buckthorns (*Frangula alnus* Miller) and compared it in two different environmental conditions (in an open field and in a plantation) at Sainte-Catherine-de-Hatley, in Southeastern Québec, Canada. Allometric equations were developed by these authors using age as independent variable and total aboveground biomass as dependent variable.

The expansion factor from the table 4.4 of IPCC (2006), value 0.46 (representing "Domain = Temperate, other broadleaf ABG <75 t/ha") was used to estimate the belowground biomass component.

Yield tables

Growth and Yield tables are forestry tools describing stand properties for individual species classified by site productivity. They contain stand dimensions such stand mean diameter at breast height (DBH), stand height (H) and number of trees/ha for the expected live-span of these stands. Hence, the stand information attributed to age 40 years can be retrieved.

The variability of the stand characteristics for a given tree species and a given locality depends on stand structure, prescribed forest management and site properties. Site properties determine productivity, hence yield tables are often classified by site index (SI) as a productivity indicator. It is usually defined as stand height that the dominant and codominant trees in fully stocked, even-aged stands attain at a given age (Fig. 2). Site index is commonly expressed by stand height that is reached at a given age and tree species. The age of 100 years is often used to assess the site index (Brandl et al., 2018). For example, for a Norway spruce forest stand in the Czech Republic, SI = 32 indicates that the dominant and codominant Norway spruce trees reach an upper height of 32 m at age 100 years. So far, 12 yield tables (each for up to 14 tree species) from four different countries (Austria, Czech Republic, the Netherlands and Spain) have been used to estimate mean stand-specific dimensions (mean tree DBH and H) at the age of 40 years for different site fertility (site index).

An example of applicable information from yield tables is shown in Fig. 2, using the source of Jansen et al. (2018). It describes the growth performance in terms of stand height across the age span for five productivity classes representing site index. Site index with the highest stand height (MAX - site index) indicates the heights that trees of a given species on a given locality would reach at a given age under the best site conditions (fertility). The poorest site conditions are represented by the lowest productivity class (MIN - site index).

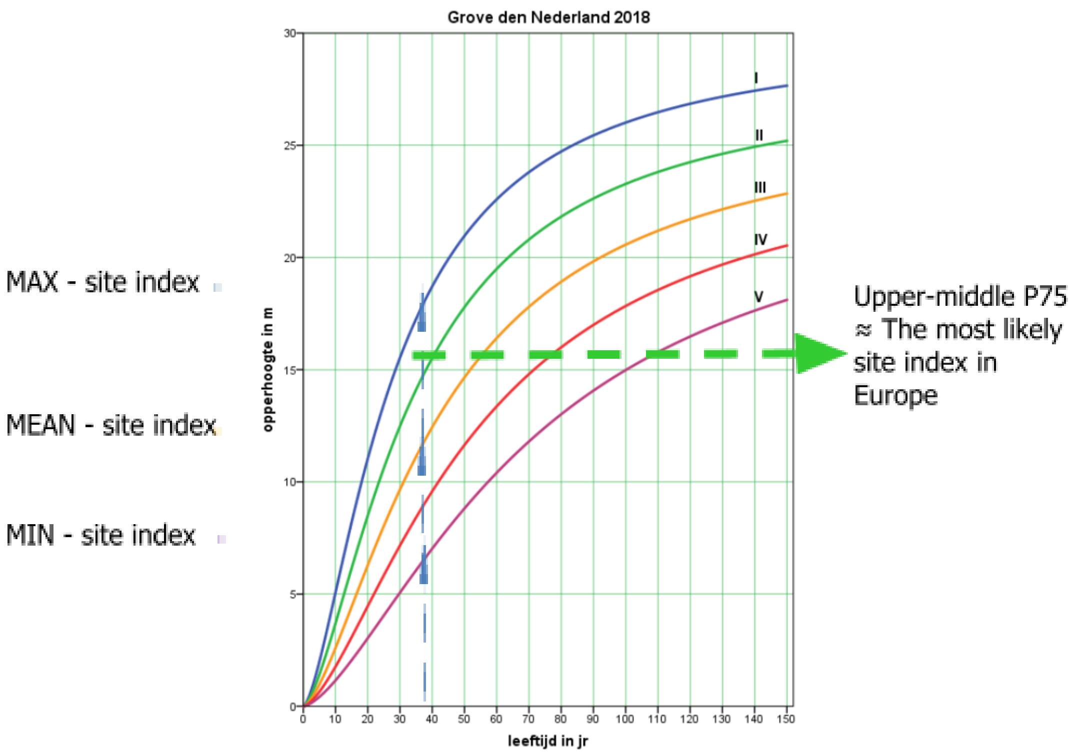

Fig. 2: Stand height development over stand age – y-axis = stand height in m, x-axis = stand age in years. MAX, MEAN, upper-middle P75, and MIN site indexes indicate the range of considered productivity for stand age 40 years. Modified from Jansen et al. (2018).

Since the specific fertility class of Life Terra plantation is mostly not determined, the estimation procedure uses National GHG Inventory Reports and NFIs to increase the accuracy of biomass and carbon estimation.

National GHG Inventory Reports and NFIs in Europe

The parties to the United Nations Framework Convention on Climate Change (UNFCCC thereon) are required to annually report their GHG emissions and removals by sources and sinks. These GHG reports often include the most up-to-date information on the local NFI and tools for tree and forest biomass estimation used. Cienciala et al. (2008b) evaluated NFI programs in Europe in terms of supplying information needed for emission inventory on forestry under UNFCCC and Kyoto Protocol. They showed that NFI programs in most countries are the major data source on forests. Therefore, they may serve for supplying the essential information in terms of quantifying above-ground biomass (among others) and carbon content that could be applicable for Life Terra.

Three key data sources are analyzed: 1) NIRs containing relevant data for biomass carbon content estimation and representative biomass functions for the country-specific tree species. 2) National sample-based forest inventories, such as NFI, that contain data on tree and stand characteristics and volumetric and/or biomass functions. 3) Yield tables from which the stand dimensions for individual species can be extracted by site productivity classes. The applicable information regarding these three sources is processed according to the guidance on biomass estimation made by Cienciala et al. (2022) to derive the representative site index, survival rate and representative tree and stand dimensions at age 40 years. The steps followed to analyze the information are summarized below.

1. A list of the country-specific tree species for Life Terra was extracted.
2. NIRs on GHG emissions and yield tables for each of the countries were analyzed. The relevant information regarding tree and stand growth, forest density and biomass functions was extracted.
3. Survival rate and site index by country, tree species, and/or species group type was estimated using available NFI data according to Cienciala et al. (2022). This estimated site index is labeled as a guiding site index (GSI) thereon.
4. Tree and stand dimensions were retrieved from yield tables using the GSI estimated in step 3. When the guiding site index was between two site productivity classes of a given yield table, a linear interpolation to extract the available dimensions at age 40 years was carried out.
5. Available tree and stand dimensions at age 40 years were also extracted from the NFI data. These tree and stand dimensions were compared with the ones retrieved from the yield tables in step 4.

The analysis of NIR and NFI was carried out specifically for the European countries where Life Terra has planted trees (September/2022) - Germany, Spain, Portugal, Italy, The Netherlands, United Kingdom, Czech Republic, Egypt, Romania, Belgium, Ireland, Greece, France, Malta, Costa Rica. Check the full report for this analysis here.

Estimation procedure for tree level biomass

To estimate tree and stand biomass in Life Terra plantations as assumed at 40 years stand age, the following steps are taken:

1. Yield table stand dimensions (DBH and H at 40 years for the published site index range) are used as input variables for the available species-specific allometric equations.
2. The outputs of the allometric equations from Step 1 were processed to get the min, mean and max total dry weight biomass [t/tree] by biogeographic regions, countries, tree species and productivity given by the three site index analyzed (mean, upper-middle (P75) and GSI)
3. The output from Step 2 was further aggregated to obtain representative tree biomass for forest type (broadleaved, coniferous), biogeographic region and productivity given by the aforementioned site indexes.
4. Life Terra database of all planted species was complemented so as to provide tree biomass estimates for all species (Annex I) using the output from Step 3 for the species beyond the guiding species where biomass estimates were available directly as specified in Step 2. This makes the biomass estimation complete at tree level.

The estimated biomass is given as, 1) a single value which was considered to be the most likely biomass that individual trees would reach at expected age 40 years, and 2) a range representing the uncertainty of the estimation according to scientific literature, yield models, and National Forest Inventories (NFIs). The individual biomass value is determined as follows:

- When GSI is known, the individual value is determined as the estimated biomass for that specific GSI.
- When GSI is missing, the mentioned individual value is determined as the average between the estimated biomass reached in mean and percentile 75 (P75) site fertility conditions of the range given in the yield models.

The range of biomass is determined as follows:

- When GSI is known, the range is established using the standard deviation (68.2%), i.e., ±34.1%.
- When GSI is missing, the range is determined as the estimated biomass reached in mean and percentile 75 (P75) site fertility conditions.

From tree level to plantation level

Life Terra database contains the number of trees per site that has been planted, with information about the species, the date of planting and its location. To upscale the biomass estimates from tree level to plantation and/or stand scale, the number of planted trees (tree count) is used. The results can be expressed in total amount of biomass [t of dry weight biomass per plantation site] or in biomass per hectare [t/ha] when the boundaries of the plantation are accurately mapped.

Mortality considerations

To estimate biomass in the future (tree/stand age of 40 years) it is important to consider tree mortality and management interventions that could reduce the number of trees per site over time. Tree planting of Life Terra includes a wide range of environments. Life Terra estimated different survival rates depending on the planting objective. The possible planting objectives in Life Terra can be:

- Ecological restoration
- Timber plantation
- Food forest/Agroforestry
- Garden
- Green infrastructure
- Other

Ecological restoration

Plantings with an ecological restoration objective seek to initiate or accelerate ecosystem recovery following damage, degradation, or destruction. Usually this means very harsh conditions (i.e. after forest fires, mines, etc.), in which is not expected very high survival rates. A survival rate of 50% could be suitable for these plantations based on experience and in other tree planting projects.

Timber plantation

Timber plantations seek growing trees to sell their wood. It is important to reinforce that Life Terra does not foster production forests of fast-growing species and only works with bigger cycles of 40 to 60 years (Life Terra has agreements with all landowners forbidding them to cut down the trees in 40 years minimum).

A more accurate assessment of survival rate can be carried out by the analysis of the applicable yield tables. The age-related decline of mean tree density (trees/ha) in timber plantations on forest land over time was assessed using yield tables by biogeographic regions, countries, tree species, group type and mean site index at different ages. For that, the number of trees/ha at planting age was derived from an exponential function that fitted the processed data (Fig. 3).

A general function was applied with the data of all biogeographic regions, countries, tree species, group type and mean site index for those cases when the number of trees/ha planting age could not be derived.

A ratio between the number of trees/ha at age 40 years and the derived number of trees/ha at planting age represents the survival rate. Since it is derived from yield tables, it includes both the effect of mortality and management interventions. Table 6 in Results provides the details of this assessment.

Note that the correction of biomass estimates due to mortality based on yield tables can only be used for plantations that use the expected planting density. If the actual planting is significantly smaller (less than ½ of the derived planting density), the mortality correction is not applicable.

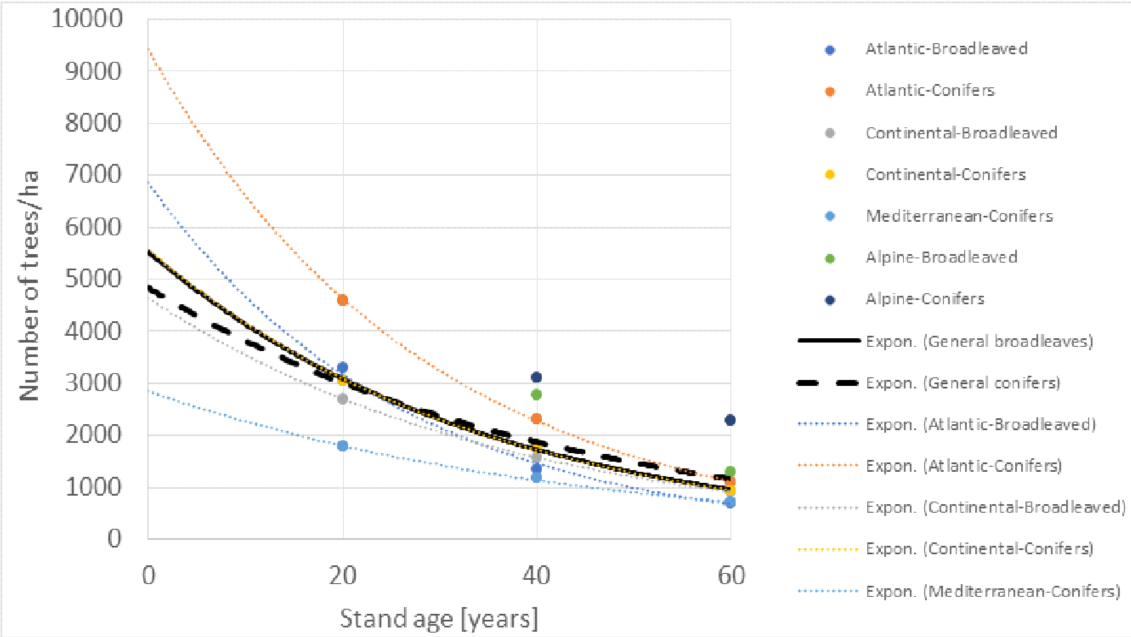

Fig. 3: Estimated trends in mean number of trees/ha over time by biogeographic regions and species group types.

Food forest/Agroforestry

Agroforestry is the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits. Plantings with this objective usually take place in cropland, which tends to be more fertile than the land where ecological restoration is needed. Additionally, these plantings are located in more accessible places, which allows easier maintenance and supervision from the landowner. Given all these aspects, it could be expected an average survival rate of 80%.

Gardens

Life Terra fosters plantings in gardens as they help to stabilize the soil, filter water, decrease surface temperature, among other benefits. Garden plantings are characterized by having easy access to water and a high degree of maintenance work, as they take place in highly accessible land. Therefore, the survival rate in gardens is expected to be on average 90%.

Green Infrastructure

Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. Despite these plantings being taken place close to maintenance structure and supervision, they are usually in very exposed areas (i.e. roads, parks, etc.) Therefore, the survival rate of green infrastructure plantings is assumed to be on average 65%.

Other

In case plantings do not fit any of the criteria above, Life Terra classifies them as "Other". This is a very broad definition and, consequently, very difficult to establish any kind of pattern. Thus, it is preferable for Life Terra to assume a conservative average survival rate of 50%.

From dry weight biomass to C, and from C to CO_2 equivalent

To express the amount of C and its CO_2 equivalent from biomass, the factor 0.5 is applied reflecting that around 50% of the biomass dry weight is C (depending on tree species can slightly change, (Thomas and Martin, 2012)). So that, amount of C ≈ 0.5*TB, where TB is total biomass [t of dry weight]. The CO_2 equivalent is calculated using a molar-weight ratio CO_2/C= 44/12.

Results

This section provides the biomass estimates at tree level, stand (plantation) level and estimates of mortality (survival rates) reflecting the methodological approaches described above.

Tree level

A list of the estimated dry weight biomass [t/tree] for three different site productivity conditions (average site index, upper-middle P75 site index, and maximum site index) by biogeographic regions, countries and tree species is shown in Table 2.

Table 2: Estimated dry weight biomass per tree at 40 years by countries, tree species and site index (SI; average, upper-middle P75 and GSI).

Country	**Species**	**Living biomass by SI [t/tree]**			**Estimated living biomass [t/tree]**		
		AVG SI	**P75**	**GSI**	**Min**	**Mean**	***Max***
Austria	*Abies alba*	0.054	0.117	-	0.054	0.086	0.117
Austria	*Fagus sylvatica*	0.084	0.128	-	0.084	0.106	0.128
Austria	*Larix decidua*	0.145	0.224	-	0.145	0.185	0.224
Austria	*Picea abies*	0.058	0.084	-	0.058	0.071	0.084
Austria	*Pinus cembra*	0.074	0.074	-	0.074	0.074	0.074
Austria	*Pinus sylvestris*	0.071	0.098	-	0.071	0.085	0.098
Czech Republic	*Abies alba*	0.130	0.235	-	0.130	0.183	0.235
Czech Republic	*Alnus glutinosa*	0.096	0.149	-	0.096	0.123	0.149
Czech Republic	*Betula pendula*	0.111	0.185	-	0.111	0.148	0.185
Czech Republic	*Carpinus betulus*	0.077	0.111	-	0.077	0.094	0.111
Czech Republic	*Fagus sylvatica*	0.079	0.134	0.092	0.061	0.092	0.123
Czech Republic	*Fraxinus excelsior*	0.215	0.388	-	0.215	0.302	0.388
Czech Republic	*Larix decidua*	0.164	0.271	0.189	0.125	0.189	0.253
Czech Republic	*Picea abies*	0.094	0.160	0.120	0.079	0.120	0.161
Czech Republic	*Pinus sylvestris*	0.086	0.154	0.131	0.086	0.131	0.176
Czech Republic	*Pseudotsuga menziesii*	0.140	0.204	-	0.140	0.172	0.204
Czech Republic	*Quercus robur*	0.088	0.159	0.075	0.049	0.075	0.101
France	*Picea abies*	-	-	0.170	0.112	0.170	0.228
France	*Pinus sylvestris*	-	-	0.098	0.065	0.098	0.131
Germany	*Fagus sylvatica*	-	-	0.021	0.014	0.021	0.028
Germany	*Picea abies*	-	-	0.077	0.051	0.077	0.103
Germany	*Pinus sylvestris*	-	-	0.051	0.034	0.051	0.068
Germany	*Pseudotsuga menziesii*	-	-	0.284	0.187	0.284	0.381
Germany	*Quercus robur*	-	-	0.079	0.052	0.079	0.106
Spain	*Juniperus oxycedrus*	-	-	0.052	0.034	0.052	0.070
Spain	*Pinus halepensis*	0.119	0.166	0.152	0.100	0.152	0.204

Country	Species	Living biomass by SI [t/tree]			Estimated living biomass [t/tree]		
		AVG SI	P75	GSI	Min	Mean	*Max*
Spain	*Pinus nigra*	0.165	0.250	0.310	0.204	0.310	0.416
Spain	*Pinus pinaster*	0.254	0.321	0.136	0.090	0.136	0.182
Spain	*Pinus pinea*	0.155	0.236	-	0.155	0.196	0.236
Spain	*Pinus ucinata*	-	-	0.112	0.074	0.112	0.150
Spain	*Pinus sylvestris*	0.095	0.136	0.065	0.043	0.065	0.087
Spain	*Quercus ilex*	0.272	0.421	0.107	0.071	0.107	0.143
Spain	*Quercus pyrenaica*	-	-	0.095	0.063	0.095	0.127
The Netherlands	*Acer pseudoplatanus*	0.243	0.298	-	0.243	0.271	0.298
The Netherlands	*Alnus glutinosa*	0.104	0.129	-	0.104	0.117	0.129
The Netherlands	*Betula pendula*	0.085	0.108	-	0.085	0.097	0.108
The Netherlands	*Fagus sylvatica*	0.171	0.266	-	0.171	0.219	0.266
The Netherlands	*Fraxinus excelsior*	0.177	0.219	-	0.177	0.198	0.219
The Netherlands	*Picea abies*	0.148	0.236	-	0.148	0.192	0.236
The Netherlands	*Pinus nigra*	0.076	0.168	-	0.076	0.122	0.168
The Netherlands	*Pinus sylvestris*	0.066	0.112	-	0.066	0.089	0.112
The Netherlands	*Populus tremula*	0.078	0.078	-	0.078	0.078	0.078
The Netherlands	*Pseudotsuga menziesii*	0.305	0.436	-	0.305	0.371	0.436
The Netherlands	*Quercus robur*	0.111	0.179	-	0.111	0.145	0.179
The Netherlands	*Quercus rubra*	0.138	0.270	-	0.138	0.204	0.270

A list of number of trees/ha for average site productivity conditions (average site index) by biogeographic regions, countries and tree species is shown in Table 3.

Table 3: Number of trees/ha at 40 years (N40y) by biogeographic regions, countries, tree species and mean site index (SI).

Bioregion	Country	Species	AVG SI	Group type	AVG N40y
Alpine	AT	*Abies alba*	30	Con.	7 106
Alpine	AT	*Fagus sylvatica*	30	Broad.	2 769
Alpine	AT	*Larix decidua*	29	Con.	1 542
Alpine	AT	*Picea abies*	27	Con.	2 274
Alpine	AT	*Pinus cembra*	16	Con.	1 512
Alpine	AT	*Pinus sylvestris*	26	Con.	3 072
Atlantic	NL	*Acer pseudoplatanus*	20	Broad.	888
Atlantic	NL	*Alnus glutinosa*	18	Broad.	1 520
Atlantic	NL	*Betula pendula*	18	Broad.	1 162
Atlantic	NL	*Fagus sylvatica*	22	Broad.	1 914
Atlantic	NL	*Fraxinus excelsior*	21	Broad.	1 207
Atlantic	NL	*Picea abies*	18	Con.	1 950
Atlantic	NL	*Pinus nigra ssp. laricio*	17	Con.	2 581
Atlantic	NL	*Pinus nigra ssp. nigra*	13	Con.	3 334
Atlantic	NL	*Pinus sylvestris*	18	Con.	2 769

Bioregion	Country	Species	AVG SI	Group type	AVG N40y
Atlantic	NL	*Populus cul.*	25	Broad.	274
Atlantic	NL	*Populus tremula*	14	Broad.	1 149
Atlantic	NL	*Pseudotsuga menziesii*	29	Con.	972
Atlantic	NL	*Quercus robur*	19	Broad.	2 023
Atlantic	NL	*Quercus rubra*	21	Broad.	1 926
Continental	CZ	*Abies alba*	28	Con.	2 406
Continental	CZ	*Alnus glutinosa*	22	Broad.	891
Continental	CZ	*Betula pendula*	20	Broad.	1 393
Continental	CZ	*Carpinus betulus*	18	Broad.	1 840
Continental	CZ	*Fagus sylvatica*	26	Broad.	2 783
Continental	CZ	*Fraxinus excelsior*	26	Broad.	1 204
Continental	CZ	*Larix decidua*	28	Con.	1 080
Continental	CZ	*Picea abies*	26	Con.	1 958
Continental	CZ	*Pinus sylvestris*	22	Con.	2 096
Continental	CZ	*Populus cul.*	28	Broad.	377
Continental	CZ	*Pseudotsuga menziesii*	34	Con.	1 195
Continental	CZ	*Quercus robur*	22	Broad.	2 562
Mediterranean	ES	*Pinus halepensis*	17	Con.	1 025
Mediterranean	ES	*Pinus nigra*	19	Con.	1 417
Mediterranean	ES	*Pinus pinaster ssp. mesogeensis*	27	Con.	704
Mediterranean	ES	*Pinus pinea*	15	Con.	578
Mediterranean	ES	*Pinus sylvestris*	24	Con.	2 124

Bioregion = biogeographic region; Broad. = Broadleaved; Con. = Conifers; AVG = average; AT = Austria; NL = Netherlands; CZ = Czech Republic; ES = Spain

A list of estimated tree dry weight biomass [t/tree] at age 40 for three different site productivity conditions (average site index, upper-middle P75 site index, and maximum site index) by biogeographic regions, countries and group type is shown in Table 4.

Table 4: Estimated dry weight biomass per tree at 40 years by biogeographic regions, countries, species group type and site index (SI; average, upper-middle P75 and maximum). Average and maximum site index is also listed.

			SI [m]		Living biomass [t/tree]		
Bioregion	**Country**	**Group type**	**AVG**	**MAX**	**AVG SI**	**P75**	***MAX SI***
Alpine	AT	Broad.	30	39	0.084	0.128	*0.172*
Alpine	AT	Con.	26	35	0.081	0.119	*0.158*
Atlantic	NL	Broad.	20	24	0.190	0.257	*0.324*
Atlantic	NL	Con.	19	26	0.139	0.224	*0.309*
Continental	CZ	Broad.	23	31	0.148	0.237	*0.325*
Continental	CZ	Con.	28	37	0.123	0.205	*0.287*
Mediterranean	ES	Broad.	30	45	0.272	0.421	*0.570*
Mediterranean	ES	Con.	20	26	0.158	0.222	*0.286*

Bioregion = biogeographic region; Broad. = Broadleaved; Con. = Conifers; AVG =average; MAX = maximum; AT = Austria; NL = Netherlands; CZ = Czech Republic; ES = Spain

Shrubs

The dry weight biomass of *Frangula alnus* aged 26 years is 0.021 t/shrub as estimated according to (Hamelin et al., 2015)

Stand (plantation) level

A list of estimated stand dry weight biomass [t/ha] at age 40 years for three different site productivity conditions (average site index, upper-middle P75 site index, and maximum site index) by biogeographic regions, countries and group type is shown in Table 5.

Table 5: Stand level estimated dry weight biomass per hectare at age 40 years by biogeographic regions, countries, species group type and site index (SI; average, upper-middle P75 and maximum). Average and maximum site index is also listed.

				SI [m]		Living biomass [t/ha]		
Bioregion	**Ctry.**	**Group type**	**N40y**	**AVG**	**MAX**	**AVG SI**	**P75**	***MAX SI***
Alpine	AT	Broad.	2 769	30.0	39.4	231.5	354.4	*477.4*
Alpine	AT	Con.	3 101	25.6	35.4	250.0	370.4	*490.7*
Atlantic	NL	Broad.	1 340	19.7	24.0	254.0	344.0	*434.0*
Atlantic	NL	Con.	2 321	18.9	25.8	323.6	520.9	*718.2*
Continental	CZ	Broad.	1 579	23.1	30.9	233.9	373.5	*513.1*
Continental	CZ	Con.	1 747	27.6	36.8	215.0	357.9	*500.8*
Mediterranean	ES	Con.	1 169	30.0	45.0	317.8	492.1	*666.4*
Mediterranean	ES	Broad.	NA	20.2	25.6	NA	NA	*NA*

Bioregion = biogeographic region; Broad. = Broadleaved; Con. = Conifers; AVG average; N40y = number of trees/ha at age 40 years; Ctry. = Country; AT = Austria; NL = Netherlands; CZ = Czech Republic; ES = Spain; NA = Not available

Countries representing biogeographic regions

A list of which countries represent each biogeographic region. This selection is based on the data available for each country and its geographical location. Table 6. The Biogeographic regions not listed still need to have a representative country assigned.

Table 6: Representative country per biogeographic region.

Biogeographic region	Representative country
Atlantic	The Netherlands
Continental	Czech Republic
Alpine	Austria
Mediterranean	Spain

Survival rates in timber plantations

A list of estimated survival rates due to tree mortality and management interventions by country and species group types for mean site index conditions is shown in Table 7.

Table 7: Mortality and management interventions effect on the reduction of number of trees over time

	Conifers		Broadleaved	
Country	**Survival rate**	**Mortality**	**Survival rate**	**Mortality**
Germany	0.368	0.632	0.326	0.674
Spain	0.551	0.449	0.551	0.449
Italy	0.603	0.397	0.551	0.449
The Netherlands	0.195	0.805	0.246	0.754
Czech Republic	0.432	0.568	0.415	0.585
Malta	0.603	0.397	0.588	0.412
Austria	0.500	0.500	0.641	0.359

Discussion

Biomass estimates – issues to consider

Consideration of species

Data from 12 yield tables (YT) from four different countries were used to aid estimation of tree living biomass at age 40 years, including the number of species and corresponding species-specific biomass functions by biogeographic regions as follows:

- 1 YT from Austria (Alpine region): 6 tree species
- 1 YT from Netherlands (Atlantic): 14 tree species
- 2 YT from the Czech Republic (Continental): 12 tree species
- 8 YT from Spain (Mediterranean): 6 tree species

Although this material is rather extensive, it remains limited considering the wide geographical scope, site conditions and plant material used in Life Terra plantation efforts. Obviously, the improved estimates can be expected once the locally specific biomass functions would be available and used instead of the substituting values made of species/plant type averages. Annex I offers guidance for Life Terra tree species for which the estimates could be made more accurate in this way.

Shrubs

The literature on biomass estimates for shrubs is severely limited. This is because shrubs have other important ecological functions such as reducing soil erosion and increasing biodiversity. These are more important than the naturally low and variable carbon sequestration capacity. The single biomass functions for *Frangula alnus* at tree (shrub) scale by Hamelin et al. (2015) used here is only a pragmatic substitute for shrub estimates that should be applied with care for shrub ecosystems established by Life Terra in European conditions. It would be advisable to use other indicators for restoring land using shrubs, such as affected area or area cover (in spatial units) instead of highly uncertain and quantitatively insignificant biomass estimates. This could also be conveniently aided by remote sensing products.

Stand level estimates

Stand scale biomass estimates are needed for large-scale biomass assessments and intercomparison of growth performance among sites and regions. It is important to stress that stand level assessment for Life Terra plantations requires accurate mapping of the actually planted area and its boundaries to make the biomass estimates per hectare trustable.

Mortality and management considerations

For the projection estimates (tree/stand age of 40 years) that are described in this text, it is important to consider the uncertainty associated with the assumed tree mortality and management interventions reducing the number of trees per site over time. This uncertainty can generally be reduced by using the available local information on growth conditions of trees and stands. This is specifically important for timber plantations.

In the adopted methodology, the initial general expert judgment of Life Terra for survival rate (40 %) was further analyzed by biogeographic region and species type providing more specific guidance on mortality (survival rate; Table 6). This assessment used information on stem density (trees/ha) at different stand age corresponding to the mean site productivity conditions as compiled in yield tables. However, this approach is also a generalization applied across a range of actual planting conditions of Life Terra sites. Additionally, some information is lacking or remain questionable – e.g., stem density information is missing for the broadleaved tree species in the Mediterranean biogeographic region and the assessed mean number of trees/ha at planting age is overly high for the conifer plantations in the Atlantic region (Fig. 3). Data on number of trees/ha at age 20 years for both broadleaves and conifers from the Alpine biogeographic regions is also limited.

A further improvement of mortality or survival rate assessment can be proposed by using the local (country-specific) sample-based National Forest Inventories (NFI) that are available in most European countries (Tomppo et al., 2010). These could help determine effects of mortality and management interventions based on the most recent empirical evidence. This approach can be demonstrated on forest inventory data in the Czech Republic. For that, data from the country-level landscape inventory project CzechTerra (Cienciala et al., 2016) was analyzed. The compilation of forestry data with respect to stem density (trees/ha) can reveal the actual age-dependency of this variable for desired species or species type (Fig. 4). That information can directly be used to assess locally specific survival rate.

Moreover, the sample-based programs such as NFIs or similar offer other usable information to be used for improving biomass assessment. Specifically, representative site indexes (stand height at 100 years) can be derived for the desired local tree species or species group or type. Using the example of Czech Republic and the sampling of CzechTerra, the representative site index in this country was assessed to be about 29 and 27 m for coniferous and broadleaved forests, respectively (Fig. 5).

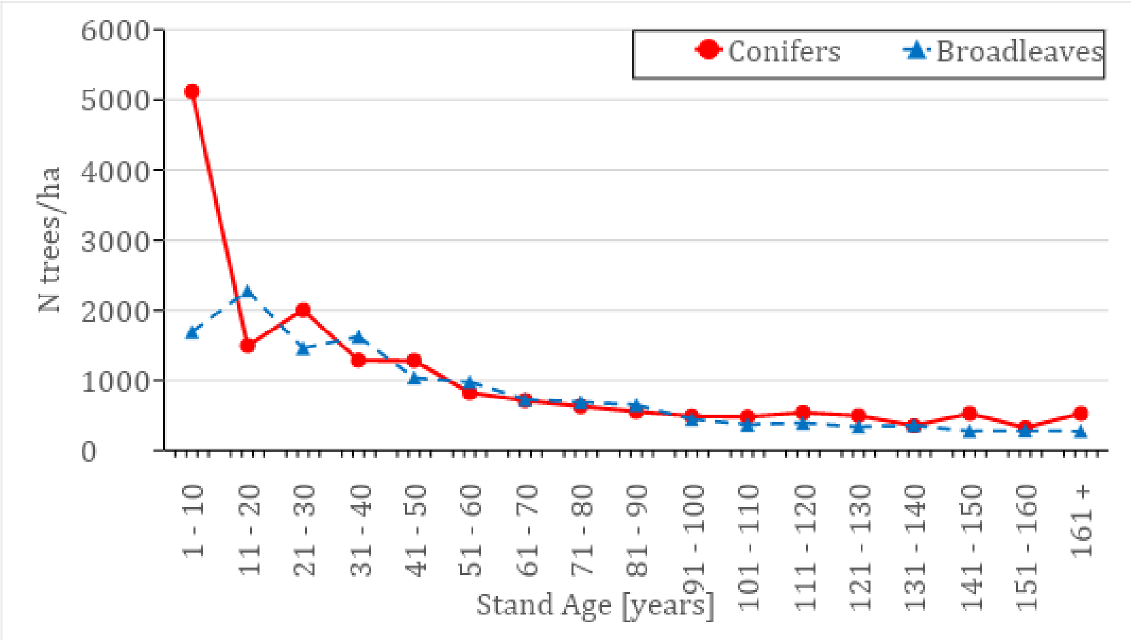

Fig. 4: Number of trees/ha by stand age in the Czech Republic. Data from the CzechTerra project.

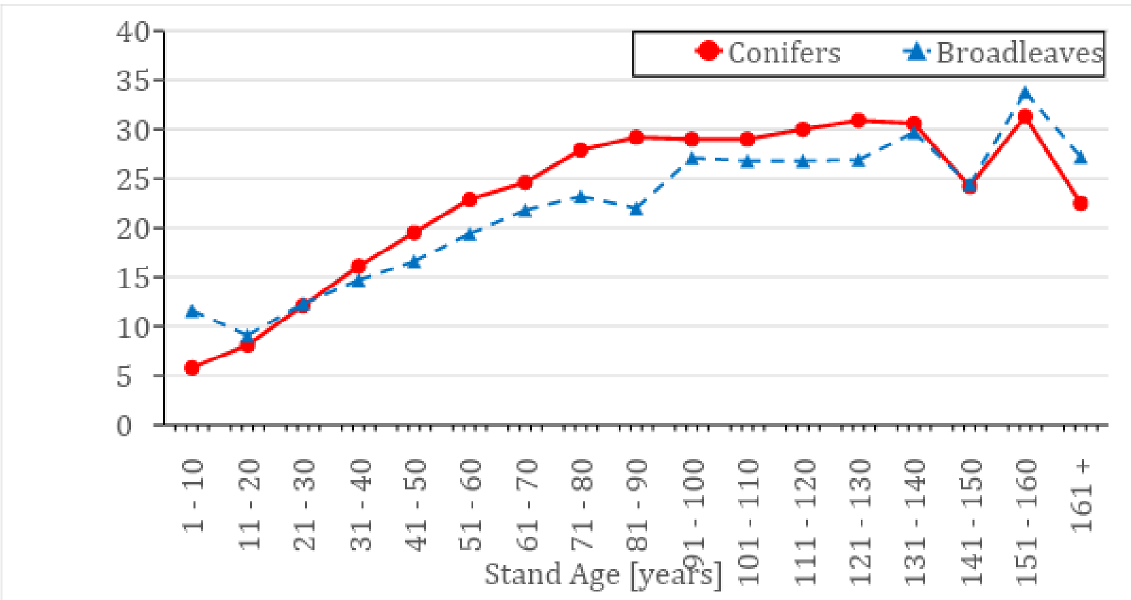

Fig. 5: Average tree height [m] by stand age in the Czech Republic. Data from the CzechTerra project.

Conclusions

The biomass estimation procedure to assess biomass growth and carbon fixation for Life Terra plantations at the assumed age 40 years is presented. It describes the methodological assumptions used and the concrete methodological steps taken to assess the likely biomass range specific to biogeographic regions and species type. It also provides the guidance for further accuracy improvements using the locally available information on forest resources.

Accuracy of biomass estimates (and hence carbon sequestration capacity) can gradually be increased by using the locally available tree biomass equations, stand yield tables and information from sample-based forest inventories. Additional sources of usable data can be retrieved from the greenhouse gas emission inventories that include country-specific methodological approaches for forestry in line with the Good Practice of Intergovernmental Panel on Climate Change (IPCC, 2006 and later). This has also been a guiding principle for the presented methodological guidance applicable for Life Terra plantation.

Also due to the above, it should be noted that this report used some qualitative and quantitative information that is actual with respect to the date of this report (September 2022). It will be gradually updated and revised in line with the available source material used for the estimation.

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LIFE19 CCM/NL/001200

Annex I

Groups of species

Table A1. 1: Groups of species

Species	Guiding species by biogeographic regions			
	Atlantic	Continental	Mediterranean	Alpine
Platanus occidentalis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Ulex parviflorus	Shrubs	Shrubs	Shrubs	Shrubs
Abies alba	*Picea abies*	*Abies alba*	Conifers	*Abies alba*
Acer campestre	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Acer monspessulanum	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Acer opalus	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Acer pseudoplatanus	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Acer tataricum	Shrubs	Shrubs	Shrubs	Shrubs
Aesculus hippocastanum	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Alnus glutinosa	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Alnus viridis	Shrubs	Shrubs	Shrubs	Shrubs
Amelanchier lamarckii	Shrubs	Shrubs	Shrubs	Shrubs
Arbutus unedo	Shrubs	Shrubs	Shrubs	Shrubs
Aronia melanocarpa	Shrubs	Shrubs	Shrubs	Shrubs
Berberis thunbergii	Shrubs	Shrubs	Shrubs	Shrubs
Berberis vulgaris	Shrubs	Shrubs	Shrubs	Shrubs
Betula alba	*Betula pendula*	*Betula pendula*	Broadleaved	Broadleaved
Betula pendula	*Betula pendula*	*Betula pendula*	Broadleaved	Broadleaved
Carpinus betulus	Broadleaved	*Carpinus betulus*	Broadleaved	Broadleaved
Casuarina sp.	Shrubs	Shrubs	Shrubs	Shrubs
Castanea sativa	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Cedrus atlantica	Conifers	*Larix decidua*	Conifers	*Larix decidua*
Cedrus libani	Conifers	*Larix decidua*	Conifers	*Larix decidua*
Celtis australis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Ceratonia siliqua	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Chamaerops humilis	Shrubs	Shrubs	Shrubs	Shrubs
Cistus albidus	Shrubs	Shrubs	Shrubs	Shrubs
Cistus ladanifer	Shrubs	Shrubs	Shrubs	Shrubs
Cistus salviifolius	Shrubs	Shrubs	Shrubs	Shrubs
Cornus kousa	Shrubs	Shrubs	Shrubs	Shrubs
Cornus mas	Shrubs	Shrubs	Shrubs	Shrubs
Corylus avellana	Shrubs	Shrubs	Shrubs	Shrubs
Corylus colurna	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Cotoneaster bullatus	Shrubs	Shrubs	Shrubs	Shrubs
Cotoneaster dielsianus	Shrubs	Shrubs	Shrubs	Shrubs
Crataegus monogyna	Shrubs	Shrubs	Shrubs	Shrubs
Cryptomeria japonica	Conifers	Conifers	Conifers	Conifers
Cupressus sempervirens	Conifers	Conifers	Conifers	Conifers

Cytisus proliferus	Shrubs	Shrubs	Shrubs	Shrubs
Elaeagnus angustifolia	Shrubs	Shrubs	Shrubs	Shrubs
Elaeagnus umbellata	Shrubs	Shrubs	Shrubs	Shrubs
Fagus sylvatica	*Fagus sylvatica*	*Fagus sylvatica*	Broadleaved	*Fagus sylvatica*
Ficus carica	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Frangula alnus	Shrubs	Shrubs	Shrubs	Shrubs
Fraxinus angustifolia	*Fraxinus excelsior*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Fraxinus excelsior	*Fraxinus excelsior*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Fraxinus ornus	*Fraxinus excelsior*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Hibiscus syriacus	Shrubs	Shrubs	Shrubs	Shrubs
Ilex aquifolium	Shrubs	Shrubs	Shrubs	Shrubs
Juglans regia	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Juniperus communis	Shrubs	Shrubs	Shrubs	Shrubs
Juniperus oxycedrus	Shrubs	Shrubs	Shrubs	Shrubs
Juniperus thurifera	Conifers	Conifers	Conifers	Conifers
Larix decidua	Conifers	*Larix decidua*	Conifers	*Larix decidua*
Ligustrum vulgare	Shrubs	Shrubs	Shrubs	Shrubs
Mahonia aquifolium	Shrubs	Shrubs	Shrubs	Shrubs
Malus sylvestris	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Medicago arborea	Shrubs	Shrubs	Shrubs	Shrubs
Melia azedarach	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Mespilus germanica	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Morus alba	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Myrtus communis	Shrubs	Shrubs	Shrubs	Shrubs
Nerium oleander	Shrubs	Shrubs	Shrubs	Shrubs
Olea europaea	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Pinus brutia	*Pinus nigra*	*Pinus sylvestris*	*Pinus nigra*	*Pinus sylvestris*
Pinus halepensis	*Pinus sylvestris*	*Pinus sylvestris*	*Pinus halepensis*	*Pinus sylvestris*
Pinus nigra	*Pinus nigra*	*Pinus sylvestris*	*Pinus nigra*	*Pinus sylvestris*
Pinus pinaster	*Pinus sylvestris*	*Pinus sylvestris*	*Pinus pinaster*	*Pinus sylvestris*
Pinus pinea	*Pinus sylvestris*	*Pinus sylvestris*	*Pinus pinea*	*Pinus sylvestris*
Pinus sylvestris	*Pinus sylvestris*	*Pinus sylvestris*	*Pinus sylvestris*	*Pinus sylvestris*
Pistacia lentiscus	Shrubs	Shrubs	Shrubs	Shrubs
Pistacia terebinthus	Shrubs	Shrubs	Shrubs	Shrubs
Platanus hispanica	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Platanus orientalis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Populus alba	*Populus tremula*	*Betula pendula*	Broadleaved	Broadleaved
Populus nigra	*Populus tremula*	*Betula pendula*	Broadleaved	Broadleaved
Populus tremula	*Populus tremula*	*Betula pendula*	Broadleaved	Broadleaved
Prunus avium	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Prunus dulcis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Prunus mahaleb	Shrubs	Shrubs	Shrubs	Shrubs

Prunus padus	Shrubs	Shrubs	Shrubs	Shrubs
Prunus spinosa	Shrubs	Shrubs	Shrubs	Shrubs
Pseudotsuga menziesii	*Pseudotsuga menziesii*	*Pseudotsuga menziesii*	Conifers	Conifers
Punica granatum	Shrubs	Shrubs	Shrubs	Shrubs
Pyrus pyraster	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Quercus cerris	*Quercus rubra*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus coccifera	Shrubs	Shrubs	Shrubs	Shrubs
Quercus faginea	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus ilex	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus macedonicus	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus petraea	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus pubescens	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus pyrenaica	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus robur	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus rubra	*Quercus rubra*	*Quercus robur*	*Quercus ilex*	Broadleaved
Quercus suber	*Quercus robur*	*Quercus robur*	*Quercus ilex*	Broadleaved
Retama sphaerocarpa	Shrubs	Shrubs	Shrubs	Shrubs
Rhamnus alpina	Shrubs	Shrubs	Shrubs	Shrubs
Rhamnus cathartica	Shrubs	Shrubs	Shrubs	Shrubs
Rhamnus frangula	Shrubs	Shrubs	Shrubs	Shrubs
Rhamnus lycioides	Shrubs	Shrubs	Shrubs	Shrubs
Ribes nigrum	Shrubs	Shrubs	Shrubs	Shrubs
RIbes rubrum	Shrubs	Shrubs	Shrubs	Shrubs
Rosa canina	Shrubs	Shrubs	Shrubs	Shrubs
Rosa rubiginosa	Shrubs	Shrubs	Shrubs	Shrubs
Rosa rugosa	Shrubs	Shrubs	Shrubs	Shrubs
Salix alba	*Populus tremula*	Broadleaved	Broadleaved	Broadleaved
Salix atrocinerea	*Populus tremula*	Broadleaved	Broadleaved	Broadleaved
Salix cinerea	Shrubs	Shrubs	Shrubs	Shrubs
Salix sp.	Shrubs	Shrubs	Shrubs	Shrubs
Sambucus nigra	Shrubs	Shrubs	Shrubs	Shrubs
Sequoiadendron giganteum	*Pseudotsuga menziesii*	*Pseudotsuga menziesii*	Conifers	Conifers
Sequoia sempervirens	Conifers	Conifers	Conifers	Conifers
Sorbus aria	Shrubs	Shrubs	Shrubs	Shrubs
Sorbus aucuparia	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Sorbus domestica	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Sorbus torminalis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Tetraclinis articulata	Conifers	Conifers	Conifers	Conifers
Tilia cordata	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
TIlia platyphyllos	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Ulmus laevis	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Ulmus minor	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Viburnum lantana	Shrubs	Shrubs	Shrubs	Shrubs
Viburnum opulus	Shrubs	Shrubs	Shrubs	Shrubs
Malus domestica	Broadleaved	Broadleaved	Broadleaved	Broadleaved

Morus nigra	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Pistacia vera	Shrubs	Shrubs	Shrubs	Shrubs
Prunus armeniaca	Broadleaved	Broadleaved	Broadleaved	Broadleaved
prunus mira	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Prunus persica	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Rubus fruticosus	Shrubs	Shrubs	Shrubs	Shrubs
Rubus idaeus	Shrubs	Shrubs	Shrubs	Shrubs
Spartium junceum	Shrubs	Shrubs	Shrubs	Shrubs
Bougainvillea glabra	Shrubs	Shrubs	Shrubs	Shrubs
Bougainvillea spectabilis	Shrubs	Shrubs	Shrubs	Shrubs
Cercis siliquastrum	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Citrus japonica	Shrubs	Shrubs	Shrubs	Shrubs
Diospyros kaki	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Diospyros virginiana	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Hibiscus rosa-sinensis	Shrubs	Shrubs	Shrubs	Shrubs
Lagerstroemia indica	Shrubs	Shrubs	Shrubs	Shrubs
Lycium barbarum	Shrubs	Shrubs	Shrubs	Shrubs
magnolia Liliiflora	Shrubs	Shrubs	Shrubs	Shrubs
magnolia stellata	Shrubs	Shrubs	Shrubs	Shrubs
Vitex agnus-castus	Shrubs	Shrubs	Shrubs	Shrubs
Genista monosperma	Shrubs	Shrubs	Shrubs	Shrubs
Tamarix gallica	Shrubs	Shrubs	Shrubs	Shrubs
Rhamnus alaternus	Shrubs	Shrubs	Shrubs	Shrubs
Buxus sempervirens	Shrubs	Shrubs	Shrubs	Shrubs
Juniperus phoenicea	Shrubs	Shrubs	Shrubs	Shrubs
Salix viminalis	Shrubs	Shrubs	Shrubs	Shrubs
Phyllirea angustifolia	Shrubs	Shrubs	Shrubs	Shrubs
Phyllirea latifolia	Shrubs	Shrubs	Shrubs	Shrubs
Abelia grandiflora	Shrubs	Shrubs	Shrubs	Shrubs
Hippophae rhamnoides	Shrubs	Shrubs	Shrubs	Shrubs
Flueggea tinctoria	Shrubs	Shrubs	Shrubs	Shrubs
Rosa sempervirens	Shrubs	Shrubs	Shrubs	Shrubs
Prunus cerasifera	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Pyrus communis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Salix salviifolia	Shrubs	Shrubs	Shrubs	Shrubs
Salix fragilis	*Populus tremula*	Broadleaved	Broadleaved	Broadleaved
Jasminum fruticans	Shrubs	Shrubs	Shrubs	Shrubs
Salix purpurea	Shrubs	Shrubs	Shrubs	Shrubs
Pyrus bourgaeana	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Viburnum tinus	Shrubs	Shrubs	Shrubs	Shrubs
Prunus domestica	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Ruscus aculeatus	Shrubs	Shrubs	Shrubs	Shrubs
Laurus nobilis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Cornus sanguinea	Shrubs	Shrubs	Shrubs	Shrubs
Picea abies	*Picea abies*	*Picea abies*	Conifers	*Picea abies*
Cytisus scoparius	Shrubs	Shrubs	Shrubs	Shrubs

Vaccinum myrtillus	Shrubs	Shrubs	Shrubs	Shrubs
Salix caprea	*Populus tremula*	Broadleaved	Broadleaved	Broadleaved
Salix trianda	Shrubs	Shrubs	Shrubs	Shrubs
Betula pubescens	*Betula pendula*	*Betula pendula*	Broadleaved	Broadleaved
Euonymus europaeus	Shrubs	Shrubs	Shrubs	Shrubs
Eucalyptus nitens	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Genista scorpus	Shrubs	Shrubs	Shrubs	Shrubs
Juglans cinerea	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Crataegus ellwangeriana	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Asimina triloba	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Cydonia oblonga	Shrubs	Shrubs	Shrubs	Shrubs
Salix babylonica	*Populus tremula*	Broadleaved	Broadleaved	Broadleaved
Liquidambar styraciflua	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Acer davidii	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Liriodendron tulipifera	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Pseudocydonia sinensis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Salix eleagnos	Shrubs	Shrubs	Shrubs	Shrubs
Anagyris foetida	Shrubs	Shrubs	Shrubs	Shrubs
Jacobaea maritima	Shrubs	Shrubs	Shrubs	Shrubs
Teucrium fruticans	Shrubs	Shrubs	Shrubs	Shrubs
Ruta graveolens	Shrubs	Shrubs	Shrubs	Shrubs
Taxus baccata	Shrubs	Shrubs	Shrubs	Shrubs
Ulmus pumila	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Ulmus glabra	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Abies grandis	*Picea abies*	*Abies alba*	Conifers	*Abies alba*
Ribes odoratum	Shrubs	Shrubs	Shrubs	Shrubs
Acer platanoides	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Actinidia arguta	Shrubs	Shrubs	Shrubs	Shrubs
Dendrocalamus asper	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Eucalyptus globulus	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Liriodendron tulipifera	*Acer pseudoplatanus*	*Fraxinus excelsior*	Broadleaved	Broadleaved
Morus bombycis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Opuntia ficus-indica	Shrubs	Shrubs	Shrubs	Shrubs
Opuntia macrocentra	Shrubs	Shrubs	Shrubs	Shrubs
Parajubaea torallyi	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Phoenix dactylifera	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Ribes nidigrolaria	Shrubs	Shrubs	Shrubs	Shrubs
Robinia pseudoacacia	*Quercus robur*	*Quercus robur*	Broadleaved	Broadleaved
Cytisus multiflorus	Shrubs	Shrubs	Shrubs	Shrubs
Diospyros lotus	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Elaeagnus multiflora	Shrubs	Shrubs	Shrubs	Shrubs
Eucalyptus camaldulensis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Genista florida	Shrubs	Shrubs	Shrubs	Shrubs

Handroanthus impetiginosus	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Maackia amurensis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Prunus cerasus	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Prunus insititia	Shrubs	Shrubs	Shrubs	Shrubs
Atriplex halimus	Shrubs	Shrubs	Shrubs	Shrubs
Vitis vinifera	Shrubs	Shrubs	Shrubs	Shrubs
Ziziphus jujuba	Shrubs	Shrubs	Shrubs	Shrubs
Erica arborea	Shrubs	Shrubs	Shrubs	Shrubs
Acacia spectabilis	Shrubs	Shrubs	Shrubs	Shrubs
Alnus cordata	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Caragana arborescens	Shrubs	Shrubs	Shrubs	Shrubs
Carya illinoinensis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Chorisia speciosa	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Citrus limon	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Citrus reticulata	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Crataegus aestivalis	Shrubs	Shrubs	Shrubs	Shrubs
Juncus effusus	Shrubs	Shrubs	Shrubs	Shrubs
Tamarix africana	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Teucrium flavum	Shrubs	Shrubs	Shrubs	Shrubs
Lonicera implexa	Shrubs	Shrubs	Shrubs	Shrubs
Vaccinium macrocarpon	Shrubs	Shrubs	Shrubs	Shrubs
Actinidia kolomikta	Shrubs	Shrubs	Shrubs	Shrubs
Alnus incana	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Amelanchier ovalis	Shrubs	Shrubs	Shrubs	Shrubs
Citrus sinensis	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Citrus unshiu	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Shepherdia argentea	Shrubs	Shrubs	Shrubs	Shrubs
Tetradium daniellii	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Myrica gale	Shrubs	Shrubs	Shrubs	Shrubs
Ligustrum japonicum	Shrubs	Shrubs	Shrubs	Shrubs
Salvia officinalis	Shrubs	Shrubs	Shrubs	Shrubs
Salvia rosmarinus	Shrubs	Shrubs	Shrubs	Shrubs
Pyracantha coccinea	Shrubs	Shrubs	Shrubs	Shrubs
Matthiola incana	Shrubs	Shrubs	Shrubs	Shrubs
Prasium majus	Shrubs	Shrubs	Shrubs	Shrubs
Decaisnea fargesii	Shrubs	Shrubs	Shrubs	Shrubs
Zanthoxylum piperitum	Shrubs	Shrubs	Shrubs	Shrubs
Citrus x junos	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Sambucus racemosa	Shrubs	Shrubs	Shrubs	Shrubs
Humulus lupulus	Shrubs	Shrubs	Shrubs	Shrubs
Ribes uva-crispa	Shrubs	Shrubs	Shrubs	Shrubs
Juglans nigra	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Ulex europaeus	Shrubs	Shrubs	Shrubs	Shrubs
Osmanthus heterophyllus	Shrubs	Shrubs	Shrubs	Shrubs
Chimonanthus praecox	Shrubs	Shrubs	Shrubs	Shrubs

Thuja occidentalis	Conifers	Conifers	Conifers	Conifers
Schinus molle	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Tilia x europaea	*Alnus glutinosa*	*Alnus glutinosa*	Broadleaved	Broadleaved
Citrus × paradisi	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Elaeagnus submacrophylla	Shrubs	Shrubs	Shrubs	Shrubs
Lonicera caerulea	Shrubs	Shrubs	Shrubs	Shrubs
Paulownia tomentosa	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Syringa vulgaris	Shrubs	Shrubs	Shrubs	Shrubs
Rubus occidentalis	Shrubs	Shrubs	Shrubs	Shrubs
Forsythia x intermedia	Shrubs	Shrubs	Shrubs	Shrubs
Aronia prunifolia	Shrubs	Shrubs	Shrubs	Shrubs
Chaenomeles japonica	Shrubs	Shrubs	Shrubs	Shrubs
Amelanchier alnifolia	Shrubs	Shrubs	Shrubs	Shrubs
Glaucium flavum	Shrubs	Shrubs	Shrubs	Shrubs
Crithmum maritimum	Shrubs	Shrubs	Shrubs	Shrubs
Ruta chalepensis	Shrubs	Shrubs	Shrubs	Shrubs
Corymbia citriodora	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Ostrya carpinifolia	Broadleaved	Broadleaved	Broadleaved	Broadleaved
Laburnum anagyroides	Shrubs	Shrubs	Shrubs	Shrubs
Paliurus spina-christi	Shrubs	Shrubs	Shrubs	Shrubs
Metasequoia glyptostroboides	Conifers	Conifers	Conifers	Conifers

LIFE19 CCM/NL/001200

Annex II

Biomass estimation example

Step-by-step biomass estimation at 40 years of age of the Life Terra plantation in Vintířov, Czech Republic.

- **Location:** Vintířov, Czech Republic (Fig. 6)
- **Objective of the plantation:** Ecological restoration
- **Area of the plantation:** 54 927 m^2 ≈ 5.49 ha

Number of trees planted: 9 765 trees ≈ 1 778 trees/ha

- *Cedrus atlantica* 2 820 trees ≈ 513 trees/ha conifers
- *Cedrus libani* 2 520 trees ≈ 459 trees/ha conifers
- *Pseudotsuga menziesii* 1 502 trees ≈ 273 trees/ha conifers
- *Quercus petraea* 2 923 trees ≈ 532 trees/ha broadleaved

Fig. 6: Location of one of the Life Terra plantations. City: Vintířov, Czech Republic.

Step 1: Country of planting

The country where the planting took place is the Czech Republic. As there is data available for the Czech Republic, the respective biomass values at tree level will be used.

- In case there was no country specific data available, the respective biogeographic region (in this case CONTINENTAL) biomass values at tree level would be used.

Step 2: Total biomass at tree level

Using the biomass values in Table 2 by country, tree species and site indexes, the following results are obtained (Table A2. 1):

Table A2. 1: Dry weight biomass for individual trees at 40 years age. Example of calculation in a Life Terra plantation located in the Czech Republic.

		Living biomass [t/tree]		
Country	**Tree species**	**Min**	**Mean**	***Max***
Czech Republic	*Cedrus atlantica*	NA	NA	*NA*
Czech Republic	*Cedrus libani*	NA	NA	*NA*
Czech Republic	*Pseudotsuga menziesii*	0.140	0.172	0.204
Czech Republic	*Quercus petraea*	NA	NA	*NA*
NA = Not available;				

As can be seen in the table above, there is no available data for three tree species (*C. atlantica*, *C. libani* and *Q. petraea*). Annex I is used to group the species.

Step 3: Groups of species

By adding the species groups in Annex I toTable A1. 1, the following table can be constructed (Table A2. 2):

Table A2. 2: Dry weight biomass for individual trees at 40 years age using groups of species. Example of calculation in a Life Terra plantation located in the Czech Republic.

			Living biomass [t/tree]		
Country	**Tree species**	**Species group**	**Min**	**Mean**	***Max***
Czech Republic	*Cedrus atlantica*	*Larix decidua*	0.125	0.189	0.253
Czech Republic	*Cedrus libani*	*Larix decidua*	0.125	0.189	0.253
Czech Republic	*Pseudotsuga menziesii*	*Pseudotsuga menziesii*	0.140	0.172	0.204
Czech Republic	*Quercus petraea*	*Quercus robur*	0.049	0.075	0.101

Step 4: Upscaling from tree level to stand level

The mathematical procedure: multiplying the total dry weight biomass [t/tree] by the total number of trees planted for each biogeographic region, tree species and site index conditions (Table A2. 3).

Table A2. 3: Total dry weight biomass at 40 years age. Example of calculation in a Life Terra plantation located in the Czech Republic.

			Living biomass [t/site]		
Country	**Tree species**	**Species group**	**Min**	**Mean**	***Max***
Czech Republic	*Cedrus atlantica*	*Larix decidua*	353	533	*714*
Czech Republic	*Cedrus libani*	*Larix decidua*	315	477	*638*
Czech Republic	*Pseudotsuga menziesii*	*Pseudotsuga menziesii*	210	258	*307*
Czech Republic	*Quercus petraea*	*Quercus robur*	143	219	*295*
		Sum	**1 021**	**1 487**	***1 954***

Another way to express the stand level dry weight biomass of the plantation is in t/ha (Table A2. 4).

Table A2. 4: Dry weight biomass [t/ha] at 40 years age. Example of calculation in a Life Terra plantation located in the Czech Republic.

			Living biomass [t/ha]		
Country	**Tree species**	**Species group**	**Min**	**Mean**	***Max***
Czech Republic	*Cedrus atlantica*	*Larix decidua*	65	97	130
Czech Republic	*Cedrus libani*	*Larix decidua*	58	87	116
Czech Republic	*P. menziesii*	*P. menziesii*	38	47	56
Czech Republic	*Quercus petraea*	*Quercus robur*	26	40	54
		Sum	**187**	**271**	**356**

Step 5: Mortality and management interventions

As the planting objective is Ecological Restoration a survival rate of 50% is assumed.

Table A2. 2: Dry weight biomass for individual trees at 40 years age using groups of species. Example of calculation in a Life Terra plantation located in the Czech Republic.

			Living biomass [t/site]		
Country	**Tree species**	**Survival rate**	**Min**	**Mean**	***Max***
Czech Republic	*Cedrus atlantica*	*0.5*	177	267	357
Czech Republic	*Cedrus libani*	*0.5*	157	239	319
Czech Republic	*Pseudotsuga menziesii*	*0.5*	105	129	153
Czech Republic	*Quercus petraea*	*0.5*	72	109	148
		Sum	**511**	**744**	**977**

Results:

Life Terra planted 9,765 trees in Vintířov. The size of the plantation was 5.49 ha. The methodology estimates that in 40 years there would be an amount of dry matter between 93 and 178 t/ha (mid-value 135 t/ha;Table A2. 4). This, expressed in tons of CO_2 equivalent, gives 171 and 326 t (248 t) of CO_2 eq./ha.