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FOREST ADAPTATION PROJECT “LINDORF”

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1 Background

The methodology employed for the Forest Adaptation Project “Lindorf” was primarily based on the standard DIN EN ISO 14064-2:2019 ”Greenhouse gases - Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements, May 2020” (Deutsches Institut für Normung, 2020). In addition to this standard, several other best practice guidance documents were consulted. These included general guidance on GHG quantification, specific guidance tailored to forest GHG projects, and literature corresponding to the current state of science. For a comprehensive reference list of all sources, please refer to the bibliography (cf. Chapter 16).

2 Terms and definitions

In this methodology, the terminology follows the definitions provided in DIN EN ISO 14064-2:2019 (Deutsches Institut für Normung, 2020). All other terms are explained below:

CO_2 certificate: Describes one (1) ton of CO_2 reduction in GHG emissions and/or enhancement in GHG removal, measured in CO_2.

Crown cover density: Measure of stand density, or the area covered by trees in a forest.

Cubic meter of timber harvested (Efm, *Erntefestmeter*)**:** Corresponds to one cubic meter standing minus bark losses and losses during harvesting.

Cubic meter standing (Vfm, *Vorratsfestmeter*)**:** Indicates the wood stock of a standing tree.

Current annual increment: Represents the annual increase in the forest stand resulting from the growth of trees.

Diameter at breast height (dbh): Diameter of a tree at a height of 1.3 m.

Ex-ante: Temporal perspective in analyses that is intended to assess the future state of the forest.

Hold over: Trees of the previous generation which are intentionally left over for value production, natural rejuvenation, or as part of a canopy over the succession stocking.

Litter cover: Last year's freshly dead organic matter that rests barely changed on the soil.

Low thinning: Trees from the lower layers are removed from the stand.

Measurement list “Kluppliste”: Includes all trees and their dbh, height, age and tree species, recorded during the sampling inventory.

Normal growing stock: Quantity measured in cubic meter standing (Vfm), which describes the prescribed growing stock of a stand or a forest management unit. The volume is defined by a yield table for the respective tree species at given age intervals.

Precommercial Thinning / Weeding: Stand regulation measure in forestry, a pure negative selection.

Project contract: Defines all rights and obligations between Pina Technologies GmbH and the forest owner for the certification of GHG projects.

Project implementer: Third party contracted by the project owner to manage the forest land.

Project owner: Owner of the forest area.

Real stock: A quantity measured in cubic meter standing, which describes the actual stock of a stand or a forest area. The stock density can be determined by comparison with the normal growing stock.

Stock density: Refers to the growing stock of a stand and is expressed in tenths of the full stocking.

Tree species distribution: Share of each tree species based on the crown area or basal area of the associated trees.

3 Description of the project

cf. DIN EN ISO 14064-2:2019 Chapter 6.2

3.1 Objective

The Forest Adaptation Project “Lindorf” primarily pursues the goal of converting pure stands into bio-diverse and structurally diverse stands, following the principle of a permanently stocked forest, which is resilient to climatic changes in the long term. Through tree-species diversification, biodiversity and other ecosystem services in the forest will be improved.

The GHG reservoir on the forested land will increase through forest adaptation activities and therefore a voluntary contribution to climate protection is made.

3.2 Activities

The project can be categorized as an Ecosystem Restoration project, following the definition of United Nations Environment Programme: Ecosystem restoration means assisting in the recovery of ecosystems that have been degraded or destroyed, as well as conserving the ecosystems that are still intact (UNEP, 2021). As such, the project type is an "Improved Forest Management" GHG project (cf. Verified Carbon Standard, 2013b): Through forest adaptation activities, the areas in the GHG project are converted from vulnerable monoculture stands into stable multi-layered mixed stands.

The project activities are selected and implemented based on the specific needs for adaptation in the stands. In particular, these are:

- Thinning and end-use of the overstory in order to develop single-tree stability and allow new growth in lower layers;
- Preregeneration based on seeds of silver fir supplemented by douglas fir, lime tree and hornbeam (depending on availability and location); and
- Encouraging and protecting natural rejuvenation (especially oak and hornbeam as well as maple)

in order to increase structural and ecological diversity in the stand.

As a result, the areas see a structural diversification in the stands and increased growth in the newly established layers, leading to removal of additional GHG emissions and an increase in the GHG reservoir. In addition, the GHG project takes an adaptive approach. At regular intervals of about three to five years, management is re-planned (cf. Chapter 11). Based on current knowledge of site conditions as well as up to date scientific insights, the most effective management measures can thus be selected.

The practical forest adaptation activities were planned by the project implementers and coordinated with Pina Technologies GmbH so that they can be depicted as realistically as possible in the TreeGrOSS forest simulation. These activities can be divided into the categories commercial timber harvest and forest maintenance, tending of young stands and precommercial thinning, planting and natural rejuvenation, and hunting.

Harvesting and forest maintenance

Harvesting and forest management ensure that high quality timber is harvested from the older stand layers, while maintaining new stand layers achieved by planting and natural rejuvenation. Furthermore, the project activities include creating space for planting new trees and facilitating natural rejuvenation through femel cutting in strips. This natural rejuvenation process is further encouraged by thinning out the existing stand to provide adequate light.

Tending of young stands and thinning

In younger stands, the main emphasis lies on tending of young trees and precommercial thinning. This involves reducing the stand density through thinning to minimize competition among trees. Additionally, the desired tree species distribution can be attained by regulating the mixture of trees in the stand. Suitable tree species for the composition of a mixed forest in the target state were identified according to recommendations published for the respective Federal States (cf. Chapter 5.2). Based on these recommendations and the tree species previously existing in the stand, the mixture of tree species in the target state was decided: Mainly silver fir, but also douglas fir, lime tree and hornbeam, are introduced through seeding. In addition, mixed tree species (mostly deciduous trees) are promoted in each stand to increase biodiversity and climate resilience. An overview of the selected tree species compositions can be found in Table 1.

Spruce	Silver Fir	Oak	Birch, Beech, Hornbeam, Lime Tree, Maple
~40%	~40%	~10%	~10%

Table 1: Mixture of tree species in the target state across the project area

Planting and natural rejuvenation

Planting / Seeding and natural rejuvenation are intended to increase growth, introduce new tree species, and create multi-layered stands. The primary goal of planting and seeding is to introduce new tree species. Tree species selection is done through the mixture of tree species mentioned in the previous paragraph. In the case of existing tree species, natural rejuvenation is preferred to planting or seeding.

Hunting

A key component to ensure rejuvenation is intensified hunting. If game populations are not controlled, browsing and peeling damage will increase, significantly reducing the number of rejuvenation plants and leading to a selection of non-climate-adapted tree species. Hunting is thus an important project measure.

3.3 Location

The "Lindorf" project area is located in the two federal states Bavaria and Baden-Württemberg and close to the Bavarian town Nördlingen. The project area covers in total 318.37 ha. The project area districts (D32, D20-22, D15, D16, D8, D11) are spread across the three different growth areas (*"Wuchsgebiete"*): *Neckarland*, *Schwäbische Alb* and *Frankenalb und Oberpfälzer Jura*. The three associated forest districts (*"Wuchsbezirke"*) are *Vorland der Ostalb*, *Mittlere Ostalb*, and *Schwäbische Riesalb*. Georeferenced shapefiles of the project area in Figures 1-3 and the maps in Annex 15.6 allow for clear identification and description of the specific extent of the GHG project.

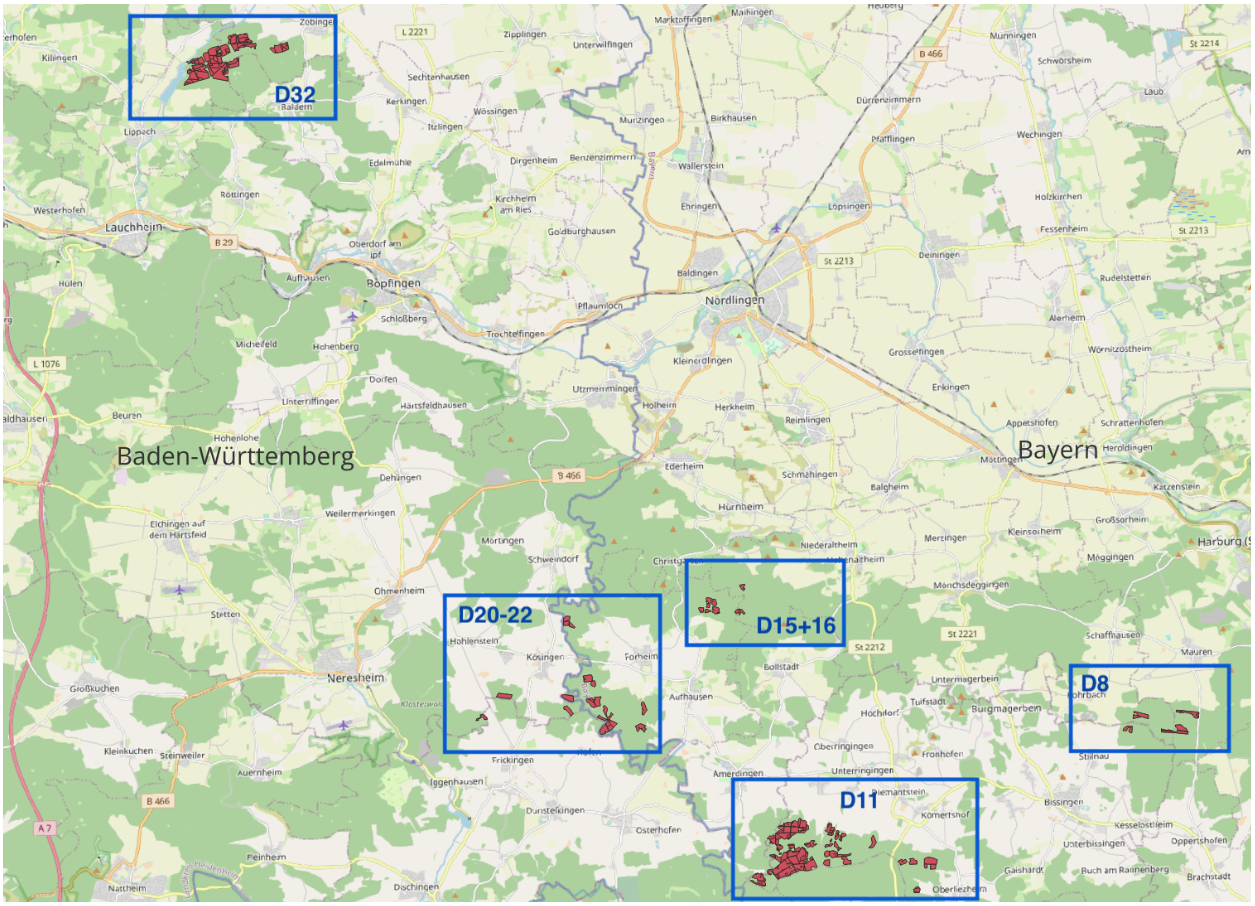

Figure 1: Map of the project area with project districts

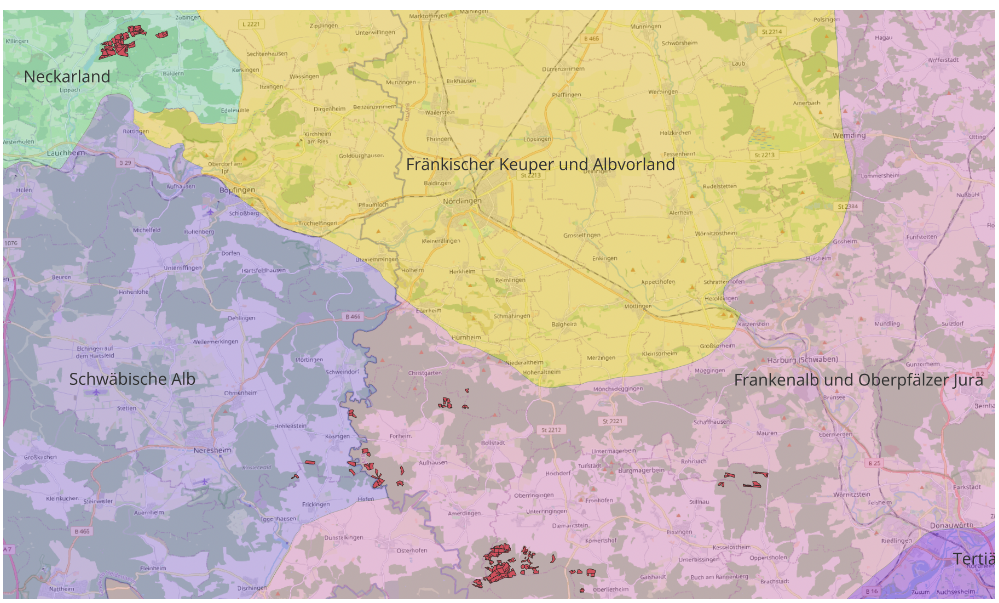

Figure 2: Growth areas ("Wuchsgebiete") of the project area

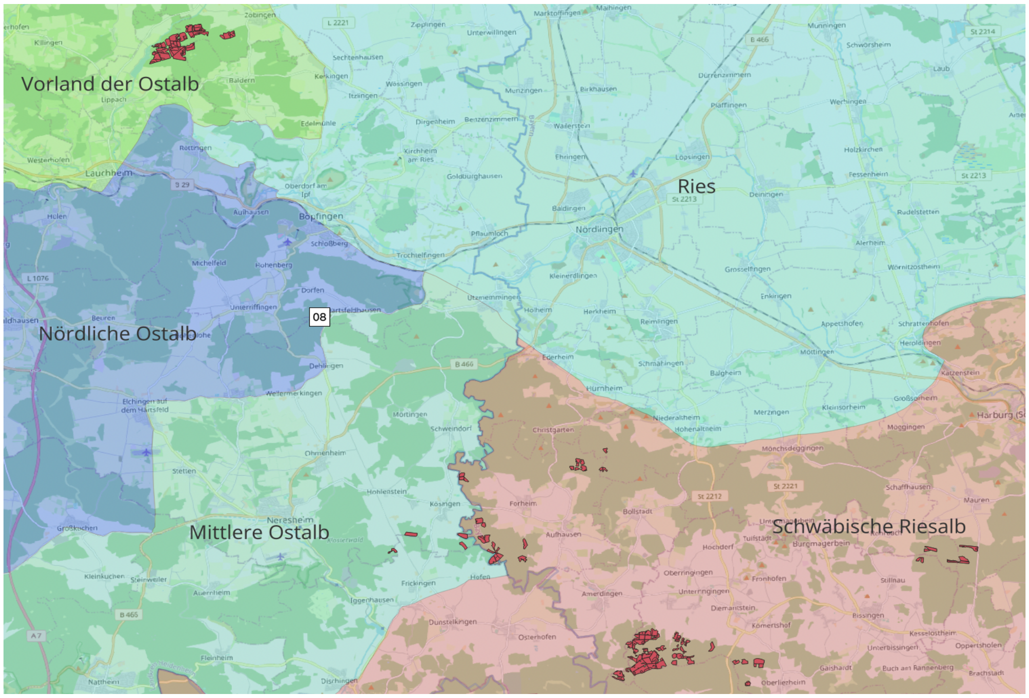

Figure 3: Forest districts ("Wuchsbezirke") of the project area

3.4 Conditions prior to project initiation

The information about climate and soil conditions of the GHG project in the following Chapters is based on the information of the respective federal states.

1) **Bavaria**: Regional information on climate are published for each forest district *("Wuchsbezirk")* in the web portal "Digitaler Baumexperte" (Bayerische Forstverwaltung, 2023). The relevant forest district located in Bavaria is the district Schwäbische Riesalb. Regional information on soil types are made available by the UmweltAtlas Bayern (Bayerisches Landesamt für Umwelt, 2023a) and allows to retrieve detailed facts about the soil types via the forest location maps "Übersichtsbodenkarte 1:25.000" (Bayerisches Landesamt für Umwelt, 2023b).
2) **Baden-Württemberg**: Regional information on climate and soil type are published by FVA Baden-Württemberg (2021) per forest district and can be viewed via the site mapping data sheets ("*Standortsdatenblätter*") for the corresponding site unit ("*Standortseinheit*").

Climate and Soils Bavaria

The average annual temperature in the Schwäbische Riesalb district is 9 °C. The average annual precipitation total is 740 mm. According to the "Übersichtsbodenkarte'' the soil types of the project area located in bavaria can be attributed to 4 categories as displayed in Figure 4: Brown earth and (shallow) brown earth over terra fusca of (skeletal) silt to clay (surface layer) *(colored in brown),* pseudogley and brown earth-pseudogley of silt to loam (loess clay) *(colored in gray)*, brown earth from silt to silty clay (loess loam) (*colored in beige*), (para-)rendzina and brown earth, low common terra fusca and pseudogley from variegated debris with wide range of soil types, common with shallow topsoil from silt to clay (*colored in pink*).

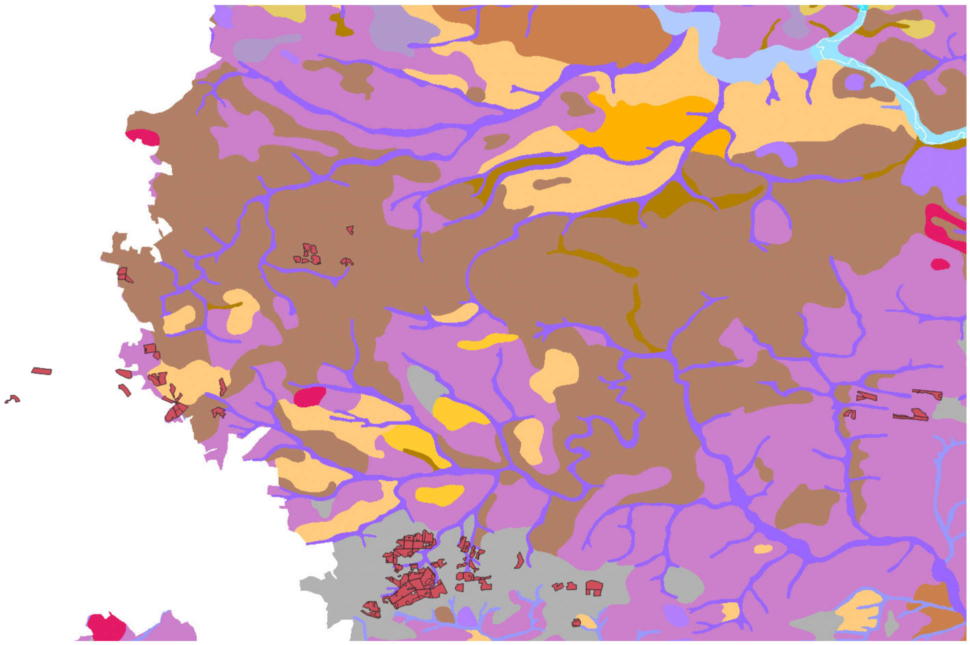

Figure 4: Soil types of the project area located in bavaria

Climate and Soils Baden-Württemberg

The average annual temperature of the Mittlere Ostalb district is 7.1 °C and the average annual precipitation total is 871 mm (climate data 1961-1990). The soil structure can be characterized as moderate to fresh layered loam, and semi-humid clay loam. The average annual temperature of the Vorland der Ostalb district is 7.7 °C and the average annual precipitation total is 877 mm (climate data 1961-1990). The soil structure can be characterized as moderate fresh clay loam to semi-humid clay loam, and semi-humid loam.

Tree species distribution

The tree species distribution of the project area refers to all layers with a total area of 318.37 ha. The tree species spruce is the leading species in 96% of the entire area and thus clearly dominates the project area.

The tree species are composed as follows:

Tree species group	Spruce	oDl[1]	oDs[1]	Other conifers	Total
Share (%)	80.8	11.4	7	0.8	100

Table 2: Tree species distribution by crown area (all layers)

Age group ratio

The age class distribution is as follows:

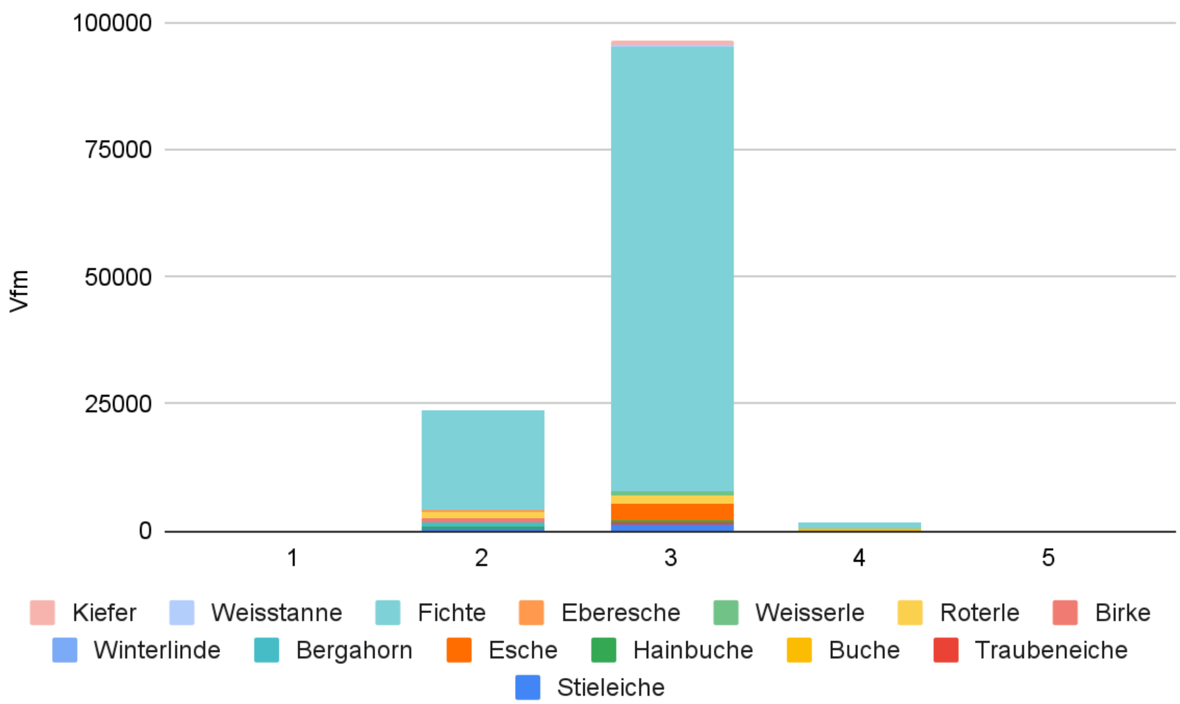

Figure 5: Age classes by tree species by stock in cubic meters (Vfm)

The age class 3 is disproportionately represented in the forest stock, with the remaining stock mainly in age class 2 and a small portion in age class 4.

Stock, degree of stocking and increment

The real stock for the project area is 121,570 cubic meters (rounded). Over all areas of the upper story, a degree of stocking of 0.9 is reported. For the individual tree species groups, the actual stock and the site class are as follows:

[1] oDs: other deciduous trees with short life expectancy
oDl: other deciduous trees with long life expectancy

Tree species group	Oak	Beech	oDl[2]	oDs[1]	Spruce	Fir	Pine
Real stock (m^3)	28,901	17,032	18,276	90,250	708,099	185	2,250
Site Index	33,7	30,6	34,5	29,1	35,2	43,9	37,2

Table 3: Actual stock and site index ("Oberhöhenbonität")

3.5 Project-related technologies and services

GHG sequestration

The GHG project's product is CO_2, which is biologically sequestered by the forest, focusing on maintaining and augmenting the GHG reservoir within the existing forest. Transitioning from age-class forest (GHG baseline) to plenter-type management (GHG project scenario) may facilitate up to a 22% increase in stemwood harvest and potentially enhance substitution performance (Johann Heinrich von Thünen-Institut, 2010). Moreover, a shift towards higher-yielding tree species, such as Douglas fir, can provide up to a 60% higher GHG sink than average (Johann Heinrich von Thünen-Institut, 2010). Additional details regarding increment, end-use, and resulting stocks are explained in Chapter 5.

Ecosystem Services

The GHG project fosters climate-resilient, productive forests, thus safeguarding habitats and vital ecosystem functions. These entail (Fachagentur Nachwachsende Rohstoffe, 2021):

1. Contributing to climate protection by mitigating GHG emissions.
2. Ensuring long-term habitat protection for flora and fauna and bolstering biodiversity through risk mitigation and biodiversity-enhancing management strategies.
3. Promoting oxygen production, air filtration and cooling, water filtration and groundwater storage by preserving and encouraging forest growth.
4. Sustaining the provision of raw materials for economic utility and job preservation, particularly in rural settings, as forests continue to be managed.
5. Preserving and enhancing the forests' recreational, health, and tourism-related value-added functions.

3.6 GHG sink

The GHG project is expected to sequester **30,263.87 t CO_2** (cf. Chapter 8) from the atmosphere over the project life of 30 years (gross GHG sink), representing the difference between the GHG baseline and

[2] oDs: other deciduous trees with short life expectancy
oDl: other deciduous trees with long life expectancy

the project (refer to Chapter 8). Stock development within the GHG project area is based on the forest simulator TreeGrOSS (cf. Chapter 8.2).

An upward trajectory of the GHG sink is projected, as illustrated in Table 4 and Figure 3. The GHG reservoir in the reference scenario refers to the total GHG reservoir capacity, consisting of the stock in the forest as it develops assuming no GHG project. It evolves from 123,945 t CO_2 in year 0 to 29,680 t CO_2 in year 30. Conversely, the GHG reservoir in the project scenario represents the reservoir associated with the project activities and forest adaptation measures delineated in Chapter 3.2, developing from 123,945 t CO_2 to 59,944 t CO_2. The gross GHG sink is computed from the difference between the GHG reservoirs in the reference and the project scenario (cf. Chapter 8.4), while the net GHG sink is derived by subtracting the risk buffer from the gross GHG sink (cf. Chapter 8.5). For this GHG project, the risk buffer is established at 18.5% (cf. Chapter 3.7). Accordingly, the net GHG sink after 30 years is **24,665.05 t CO_2**. The issued certificate volume corresponds to the total net GHG sink after 30 years (cf. Chapter 8.6). One certificate represents the value of one (1) ton of CO_2.

Year	GHG reservoir Reference scenario [CO_2]	GHG reservoir Project scenario [CO_2]	Gross GHG sink [CO_2]	Risk buffer [CO_2]	Net GHG sink [CO_2]
0	123,945	123,945	0	0	0
5	116,603	119,002	2,399	444	1,955
10	113,031	116,307	3,277	606	2,670
15	88,047	108,474	20,427	3,779	16,648
20	58,353	81,970	23,617	4,369	19,248
25	37,138	61,593	24,456	4,524	19,931
30	29,680	59,944	30,264	5,599	**24,665**

Table 4: Development of GHG reservoirs in both project and reference scenarios over project lifetime, and total GHG sink performance (all values rounded).

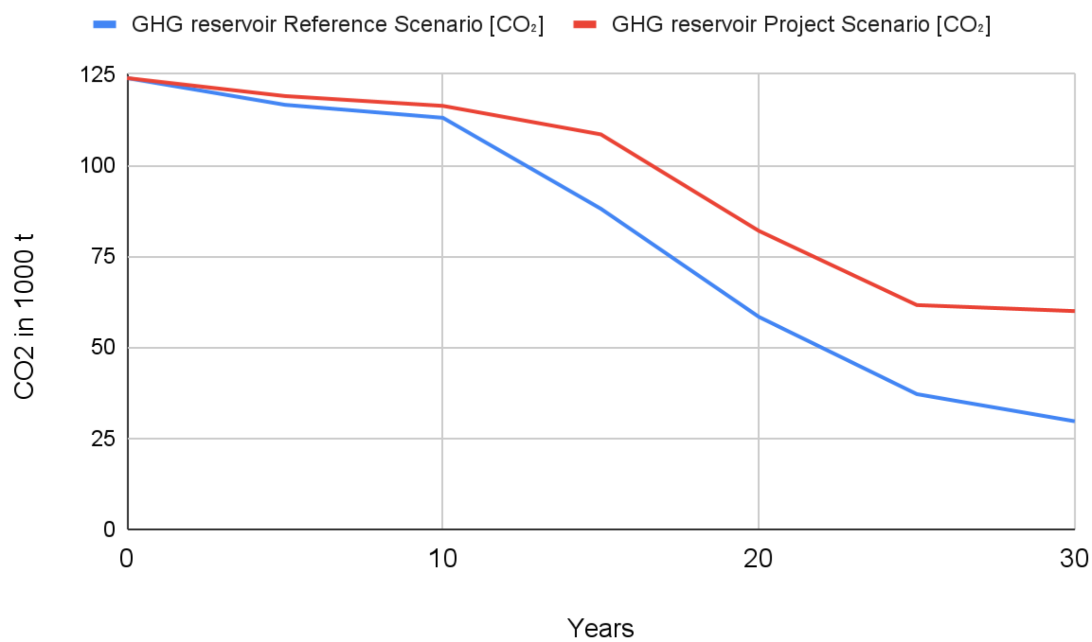

Figure 6: Projected GHG reservoir in the project and reference scenario

More detailed information is available in Annex 15.5. Pina Technologies GmbH reserves the right to correct the original prediction if new insights emerge from validation and/or scientific developments.

3.7 Risks

Employing the AFOLU (Agriculture, Forestry, and Other Land Use) Non-Permanence Risk Tool from the Verified Carbon Standard (Verified Carbon Standard, 2019), the GHG project considers internal, external, and natural risks. The total risk of **18.5%** is the sum of internal (15%), external (0%), and natural risks (3.5%). Activity shifting or market leakage effects can be excluded by the GHG project.

Internal risk

Internal risk is composed of four dimensions: Project management risk, financial viability, opportunity cost risk, and project longevity risk.

- **Project Management Risk:** The project implementers are qualified forest managers with many years of relevant experience, who are contractually bound to execute the adaptation activities (cf. Chapter 3.2). According to the 2021 Corruption Perception Index, there is a limited likelihood of external actors illicitly harvesting timber from the project area in Germany and this risk is thus excluded (Transparency International e.V., 2022). Consequently, the project management risk is **0%**.

- **Financial Risk**: The project owner as well as the project implementers can realistically estimate the costs associated with forest adaptation based on their extensive experience. Both parties have the necessary financial means to successfully implement the GHG project and to maintain it beyond its duration. In addition, the percentage of agricultural businesses that filed for bankruptcy was 0.06% in 2010, 0.05% in 2013 and 2016, and 0.04% in 2020 (Destatis, 2022). Due to these low percentages, the risk of insolvency in the forestry sector is also considered insignificant. Accordingly, the financial risk is **0%**. (Verified Carbon Standard, 2019).
- **Opportunity Cost Risk**: The analysis is based on alternative land use scenarios: In Germany, the change in land use is very unlikely due to restrictive regulations such as the Federal Forest Act §9 (Bundeswaldgesetz, 1975), which ensures that the performance capabilities of the natural ecosystem is not impaired. Furthermore, Germany has committed to forest conservation and augmentation through initiatives like the 'Glasgow Leaders' Declaration on Forests and Land Use' (UN Climate Change Conference UK, 2021). Also, considering the consistent increment of total forest area since 1990 (Umweltbundesamt, 2023), the risk of opportunity cost is **0%** (Verified Carbon Standard, 2019).
- **Project Longevity Risk**: With a project lifespan of 30 years and governed by a legally binding contract (see Annex 15.2), the project longevity risk is **15%** (Verified Carbon Standard, 2019) and calculated as follows:.

F1:
$$RiskToProjectLongevity[\%] = 30 - \frac{ProjectLife[Years]}{2}$$

External risk

External risk is composed of three dimensions: Land and resource tenure, community engagement, and political risk.

- Both land/resource access/use rights are held by the same person, the project owner. Potential conflicts over ownership and use of the project area are therefore eliminated. Land tenure and resource access risk for the GHG project is set at **0%**. (Verified Carbon Standard, 2019).

- Community Engagement: This dimension is not assessed for the GHG project, as the local community is not dependent on the project area for crucial resources like food, fuel, or construction materials (Verified Carbon Standard, 2019).

- Political risk assessment is based on the country average over the last five years of the' Worldwide Governance Indicators' (WGI) (Worldbank, 2022). For the latest available data from 2017-2021, Germany receives a score of 1.45, as shown in Table 5. Since the score falls in the lowest risk category (0.82 or higher) of the WGIs, the risk is minimal. Accordingly, the political risk for the GHG project is **0%** (Verified Carbon Standard, 2019).

Indicators	2017	2018	2019	2020	2021	Average 2017 - 2021
Participation and accountability	1.43	1.43	1.36	1.38	1.43	1.41
Political stability and absence of violence	0.59	0.59	0.57	0.68	0.76	0.64
Government effectiveness	1.65	1.59	1.52	1.35	1.33	1.49
Quality of legislation	1.78	1.76	1.72	1.59	1.63	1.70
Rule of Law	1.60	1.62	1.61	1.55	1.61	1.60
Corruption control	1.84	1.93	1.90	1.86	1.81	1.87
Average of all indicators per year	1.49	1.49	1.45	1.40	1.43	**1.45**

Table 5: Political risk

Natural risk

The natural risk for the GHG project includes the most relevant events including forest fires, storms, and insects (Hanewinkel, Hummel, & Albrechts, 2010). The detailed estimation of each factor is based on current scientific sources and, in addition to an explanation of the data basis, is provided in Annex 15.3. Here, storm risk is the highest at 2.5%, followed by insect risk and fire risk at 0.5%. Geologic risk is considered negligible because there are no significant geologic features or dynamics in the project region that affect forest conditions. The planned activities (see Chapter 3.2), both diversification with climate-resilient and native tree species and increasing structural diversity, mitigate these natural risks (Brandl, Paul, Knoke, & Falk, 2020). Due to these preventive measures, a mitigation factor of 0.5 is assumed. Thus, the total natural risk is **3.5%**.

Leakage risk

"Leakage is defined as any increase in GHG emissions that occurs outside the project boundary (but within the same country), and is measurable and attributable to the project activities" (VCS 2013b). Both internal (activity shifting) and external (market) leakage were considered with regards to timber removal volumes and resulting changes in GHG emissions.

In this GHG project, total usage volumes (harvesting and thinning) in the baseline (average of 634.9 Vfm/ha, cumulative over 30 years) is very similar to the project scenario (average of 651.8 Vfm/ha, cum. over 30 years). As more timber is produced in the project compared to the baseline, market and activity shifting leakage effects in terms of a reduction of timber supply can thus be considered neglectable.

3.8 Roles and responsibilities

The following is a list of the key players in the GHG project:

- **Project owner and implementer:** The project owner and implementer is Fürst Wallerstein Forstbetriebe, represented by Dr. Christian Wippermann. The project owner is free to decide on the management of the forest within the legal framework. This includes the implementation of the project activities. As professional forest managers, Dr. Wippermann and his team have extensive experience in forest adaptation.

- **Project developer:** Pina Technologies GmbH has developed the GHG project. A project contract was concluded with the project owner, authorizing Pina Technologies GmbH to develop and manage the GHG project. Pina Technologies GmbH also manages the project register.

Actors	Project owner and implementer	Project developer
Company	Fürst Wallerstein Forstbetriebe	Pina Technologies GmbH
Name	Dr. Christian Wippermann	Florian Fincke
Address	Bei den Kornschrannen 7 86720 Nördlingen	Vogelanger 7 82319 Starnberg
Phone number	+49 9081/805 26-0	+49 15904163004

Table 6: Contact details of main actors

3.9 Environmental Impact Assessment

The GHG Project is not a project affected by the Law on Environmental Impact Assessment (“Gesetz über die Umweltverträglichkeitsprüfung (UVPG)”). Thus, national legislation and regulations do not mandate an environmental impact assessment for the project.

3.10 Consultation

The GHG project is being carried out on private land, and since the project activities don't affect any external stakeholders, no additional consultations were needed for the project.

3.11 Chronological plan

The following is a list of dates with respect to the project plan:

- **08-09/2020:** Sampling of forest inventory data.
- **02/2021:** Date of **initiating project activities**, continuation over the lifetime of the project as stated in the project contract.
- **09-10/2023**: Acquisition, analysis, and modeling of data, using forest inventory data to quantify GHG emissions and/or removals (refer to Chapter 8).
- **10/2023:** The project description "Forest Adaptation Project Lindorf" was completed and submitted to the validators and verifiers. After validation and verification, the GHG project will be registered and the CO_2-credits will be sold (ex-ante, but only after).
- **03/2021 - 02/2051:** The GHG project has a planned duration of 30 years, which also applies to the GHG baseline and the project scenario. It's possible to extend this period, but the total duration must not exceed 60 years. Verification of the GHG project will be conducted at intervals of 3, 6, 10, 15, 20, 25, and 30 years after project start. Once the GHG project has been successfully certified, the CO_2 credits (as outlined in Chapter 8) will be sold. The results of the project certification are then published in a report.
- **03/2051:** Project activities are expected to continue beyond the termination date of the project.

Hence, the project duration spans from 01.02.2021 (date of first seeding activities on 33 hectares in the project area) to 31.01.2051.

3.12 Eligibility

Pina Earth has established specific participation conditions that apply to all GHG projects, enhancing the integrity assurance of the projects. This particular GHG project has been confirmed to comply with these conditions. The following generally applicable participation requirements must be met:

Location

- The GHG project area is a forest in accordance with the Federal Forest Act § 2 (Bundeswaldgesetz, 1975).
- The GHG project area is located in Germany. Therefore, national / site specific data, models and laws are applicable.
- A bird reserve is designated within the project area in District 8. However, this does not affect project activities or implementation. Otherwise, the rest of the project area does not fall within a national park, natural monument, nature park, or Natura 2000 site. This was confirmed using the

Geoportal BFN (Bundesamt für Naturschutz, Version 2.0, 2015), ensuring that the GHG project area has no existing legal restrictions or prohibitions on commercial timber harvesting. Consequently, all planned activities for the project may be implemented.

Ownership structure

- The project owner has contractually assured that he/she is the owner of the GHG project area and thus legally authorized to implement the activities.
- The GHG project area is privately or corporately owned (cf. Annex 15.1).

Qualifications

The project implementer has comprehensible and extensive experience in the field of forest adaptation. The following evidence is accepted in this regard:

- Certificate of completion of vocational training as a forester or similar
- Official (technical) university certificate of graduation from a forestry program or similar programs
- Work certificates as proof of at least 3 years of relevant professional experience in forestry as the main occupation
- Trade register excerpt of the project implementer in the field of forestry consulting or similar

Subsidies

The project owner has contractually assured that he or she will not receive 100% public funding for the planned project activities (see Chapter 5.2). Furthermore, the project owner will not receive any funding for the GHG emission reduction. Consequently, the additional income generated will be fully reinvested in the forest adaptation project.

GHG Programs

- The project owner has not been rejected by or participated in any GHG project in the past.
- The project owner has contractually assured that the GHG project will not be submitted to any other GHG program during the project period.

Contractual relationship

The project owner and the project developer have entered into a project agreement that includes all relevant provisions for the GHG project, in particular the commitment of the project owner to implementing the project activities and the authorization for the project developer to market the GHG emission reductions in the voluntary market.

Ecological diversity

- When selecting the tree species that shall make up the target state of the forest, the project owner shall ensure that they are site-appropriate and, if possible, native. This means that the choice of tree species either corresponds to a scientific recommendation of a recognized research institute, taking into account current climate and climate impact scenarios, or are proven to perform good growth and site adaptation on the project area.
- The project owner shall ensure that, after 30 years, at least three (3) future, site-appropriate tree species are established in the understory, whereas each species shall take up a minimum of 10% and maximum 50%. If more than three species make up the tree composition, the minimum value can be less than 10%.
- The project owner commits to increasing the diversity of tree species in the forest stand composition at the end of the crediting period through management. For this reason, the Shannon Index for tree species diversity must improve with each monitoring of the GHG project (cf. Chapter 11.4).

Laws

The GHG project complies with all laws that apply in Germany at federal, state, or municipal level. These include, in particular, the Federal Forest Act and Federal Nature Conservation Act, as well as the respective State Forest Act and State Nature Conservation Act.

4 Identifying GHG SSRs relevant to the project

Cf. DIN EN ISO 14064-2:2019 Chapter 6.3

The relevant GHG SSR were calculated following the VCS methodology 'VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.2' (Verified Carbon Standard, 2013b).

4.1 Selection of carbon pools

Carbon pool	Selected?	Justification
Above-ground living Tree Biomass Pool	Yes	Major carbon pool subject to changes from the baseline to the project scenario. The carbon pool is controlled by the project implementer.
Below-ground living Biomass Pool	Yes	Major carbon pool subject to changes from the baseline to the project scenario. The carbon pool is controlled by the project implementer.

Other living above-/below-ground Biomass Pool (e.g. shrubs)	No	Excluded due to its negligible impact (de minimis); minor carbon pool subject to changes from the baseline to the project scenario.
Dead Wood Pool (above-/below-ground)	No	The project activities do not include significant changes related to dead wood. Minor carbon pool subject to changes from the baseline to the project scenario. Dead wood is therefore excluded due to insignificance (de minimis).
Litter Pool	No	Litter is a minor carbon pool (de minimis) and is generally considered as a transitional pool only.
Soil Carbon Pool	No	The project activities do not include significant changes in terms of soil carbon, if at all, they would be slightly positive. Therefore, it is only a minor contributor to changes from the baseline to the project scenario. Soil carbon is excluded due to insignificance (de minimis).
Wood Products Pool	No	Carbon pool not included - out of project scope

Table 7: Selection of Carbon Pools

4.2 Emission sources

Emission source	Selected?	Justification
Use of Fertilizers	No	Neither the project scenario nor the baseline scenario include the use of fertilizers, so these emission sources are excluded.
Burning of Biomass (on site slash burning).	No	Neither the project scenario nor the baseline scenario include slash-and-burn, so these emission sources are excluded.
Combustion of Fossil Fuels by Vehicles / Equipment	No	Carbon emissions from harvesting equipment, log transport, and primary forest product manufacturing are not included (de minimis) because there is no significant difference between the project scenario and the baseline scenario.

Table 8: Emission Sources Included / Excluded from the Project Boundary

5 Determining the GHG baseline

cf. DIN EN ISO 14064-2:2019 Chapter 6.4

5.1 GHG baseline assumptions

In the GHG baseline, the forest continues to be used within the framework of an economically and commercially oriented forestry. The literature defines this scenario as a ‘revenue focussed forestry strategy’ (Duda, 2006). The predominant stocking structure of the project area and still predominant operational form in Bavaria and Baden-Württemberg is the age-class forest. Therefore, there are still large forest stands in which vertical and horizontal structural diversity is not satisfactorily present. This lack of diversity can be observed, among other indicators, in the data from the National Forest Inventory:

Only approximately 11.9% of the spruce forest area in Bavaria and 14.7% of the coniferous forest area in Baden-Württemberg exhibit multi-layered or plentered structures (Johann Heinrich von Thünen-Institut, 2012). When rated on a near-natural scale from 1 (very natural) to 5 (heavily culture-dominated), merely 44% in Bavaria and 35% in Baden-Württemberg achieve a rating of 1 or 2 (Johann Heinrich von Thünen-Institut, 2012).

Clear-cutting should be avoided according to Bavarian law (BayWaldG 2005, Art. 14) and needs permission according to Baden-Württemberg law (LwaldG 1995, §15). Consequently, the GHG baseline does not simulate clear-cutting, but single tree removal. In the GHG baseline, the predominantly single-layer pure spruce stand, as characterized in the baseline, aligns with the average silviculture in the region and would be preserved in the absence of the GHG project. Whenever the GHG project undergoes monitoring, the assumptions underpinning the GHG baseline are reassessed. Should there be notable changes to the reference scenario, it will be adjusted accordingly. Based on the prevailing state of scientific understanding, the GHG baseline - that is, conventional management - is defined in a standardized fashion through the following parameters for simulating future development:

End use

In the GHG baseline, a standard routine from TreeGrOSS is used to simulate harvesting by target diameter over a predetermined period. The target diameter is derived from stock data in the National Forest Inventory (Johann Heinrich von Thünen-Institut, 2012) by growth area and tree species and is determined as follows:

- The stock and dbhs in the Growth Areas (“Wuchsgebiete”) are clustered for each tree species, displayed by dbh groups, and analyzed. The table then shows, for example, the stock and average dbh of spruce, divided by dbh groups in 10cm steps on the X-axis and the Growth Areas on the Y-axis:

	Diameter at breast height in cm									
	7.0 - 9.9	10.0 - 19.9	20.0 - 29.9	30.0 - 39.9	40.0 - 49.9	50.0 - 59.9	60.0 - 69.9	70.0 - 79.9	80.0 - 89.9	>90
Stock in 1,000m^3	383	5,952	11,290	**15,194**	**12,227**	6,297	1,473	531	30	5
dbh in cm	9	15	25	**35**	**44**	54	64	74	81	92

Table 9: Spruce stock and average dbh in the growth area "Frankenalb und Oberpfälzer Jura"

- An algorithm finds the inflection point - highest stock - and then takes the average of the dbh of this column value and the adjacent point to the right, due to conservativity. In this example the highest stock appears in the column 30-39,9cm. Therefore the resulting target diameter would be (35+44)/2 = 39.5 cm. If the adjacent point is a plateau (the absolute difference is less than 5 %), then we conservatively assume that is the inflection point.
- If there is insufficient data for one species in a particular Growth Area to provide a representative value, the same analysis is done using data from the forest landscape (next larger spatial resolution). Insufficiency is defined as a target diameter equal 0, a target diameter being more than 10 cm away from the equivalent forest landscape value or the plot standard error is greater than 10%.
- All of these values have been compared to and are consistent with state-level recommendations (where available)
- When the project is spread over multiple growth areas, the maximum target diameter of all of the involved is used for conservative reasons.

The harvesting of trees is started when 30% of the main tree species in a stand have reached the target diameter. Harvesting occurs stepwise over a specified end use period per tree species. This period is defined according to Duda (2006).

Tree species	**Harvesting period (years)**
Oak	10
Beech	30
Other Softwoods	30
oDs	10
Spruce	20
Douglas Fir	20
Pine	20
Larch	20

Table 10: End-use period per tree species

The amount harvested per 5-year simulation step is distributed linearly over the end use period. For spruce an end use period of 20 years is defined, hence in the baseline scenario 25% of the spruce stock stockis harvested each time over 4 consecutive simulation steps. In each harvesting event, 50% of the trees with dbh > target diameter and 50% of the trees with dbh < target diameter are removed.

To maintain a conservative approach, the minimum degree of crown cover is left at the default value of 20% (from TreeGrOSS) in order to exclude clear-cutting in the reference scenario.

Thinning

In order to represent an average thinning in the reference scenario, a target density is defined for the project area. The target degree of stocking is derived from data of the National Forest Inventory and formulas from TreeGrOSS version 22.03. Values were calculated for each main tree species in each federal state:

1. Basal area (in m^2), mean height (in m) and dbh (in cm) for each tree species group of each federal state for age classes V (81-100 years) and VI (101-120)
2. Using the "Maximum Density" function stored for each tree species in TreeGrOSS (input variables species, dbh and height), the maximum basal area is calculated
3. To calculate the target density, the average of the ratios of basal area to maximum basal area of both age classes is calculated:

F2:

$$B^{\circ} = \frac{\frac{G_V}{G_{max,V}} + \frac{G_{VI}}{G_{max,VI}}}{2}$$

The variables are defined as follows:

- B° = target degree of stocking
- G_V = basal area of age class V
- $G_{max,V}$ = Maximum basal area of age class V
- G_{VI} = Basal area of age class VI
- $G_{max,VI}$ = Maximum basal area of age class VI

The result for spruce stands in Bavaria (0.85) and Baden-Württemberg (0.79) is a degree of stocking of 0.85.

Natural rejuvenation, sowing, planting and hunting

In the GHG baseline, the tree species composition does not change over the project period. New trees are planted as soon as a stand falls below a 25% crown cover level, ensuring that stands are never fully depleted. Both the tree species composition and age classes don’t change, maintaining the stand in its original composition. Contrary to the GHG project scenario, intensification of hunting does not occur. Consequently, the number of regeneration plants is reduced to 22% (refer to Chapter 8.2). This analysis is based on a study examining the impacts of game browsing on the condition of natural rejuvenation in Germany and the Czech Republic (Fuchs, Vacek, Vacek, & Gallo, 2021). The findings indicate that without hunting, an average of 78% of natural rejuvenation was damaged by browsing across tree species. Browsing also influences the quality and abundance of natural rejuvenation. Therefore, only 22% of the natural rejuvenation remains intact.

Ultimately, increment and use in the GHG baseline balance out over the term. The tree species distribution changes insignificantly compared to the baseline.

5.2 Differences to the GHG project scenario

The GHG project scenario is described as follows: with the GHG project, the forest will be managed in a more sustainable and near-natural way in the future. The goal is to establish a near-natural permanent forest (Möller, 1992; Landesbetrieb Forst Baden-Württemberg, 2014). The near-natural management (cf. Chapter 3.2) differs from the classic one by the following parameters:

End use and Thinning

Years 1-5	Thinning of overstory and / or regeneration felling in a strip femel system. For stands with an average age of 20-40 years, a degree of stocking of 0.7 - 0.8 is targeted and an average stock of 310-330 Vfm/ha. In older stands with trees averaged 40-80 years, the target degree of stocking is 0.8 - 0.9 and the targeted average stock 410-430 Vfm/ha. The minimum target diameter is 40 cm.
Years 6-10	Continued thinning and regeneration felling using strip femel cutting. The target degree of stocking for all stands is 0.7 - 0.8. The target stock for the younger stands is reduced to 340-360 Vfm/ha; for older stands 370-390 Vfm/ha.
Years 11-15	Stepwise removal of the overstory over the next 20 years. Further reduction of the target degree of stocking to 0.7 and the overall stock to 320-340 Vfm/ha (younger stands), respectively 330-350 Vfm/ha (older stands).
Years 16-25	Continued overstory removal, with a targeted stock of 125-140 Vfm/ha in the overstory (for hold-over trees and remaining older tree blocks)
Years 26-30	Continued overstory removal, with a targeted stock of 85 Vfm/ha in the overstory

Table 11: Project activities for overstory management over the project lifetime

Natural rejuvenation, sowing, planting, and hunting

The new regeneration layer in the project area will mostly be achieved by advance reproduction through seeding of silver fir, and supplemented with douglas fir, lime tree and hornbeam. In addition, tree species naturally occurring on the project area like oak, hornbeam and maple, will be promoted to become part of the new regeneration layer. The following table shows the seeding plan for the project area for the years 0 to 7 of the GHG project.

	Achieved			Planned			
District	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
8						19.50	
11	29.46	29.20	49.26	26.40			
15				7.70			
16				9.90			
20							4.40
21	3.55						29.70
22							6.80
32							23.00
	33.01	29.20	49.26	44.00	50.50	48.50	63.90

Table 12: Seeding plan in hectares per year per forest district

The targeted tree species composition across the entire project area is 40% spruce, 40% silver fir, 10% oak, and 10% made up of birch, beech, maple, lime tree and hornbeam. These target tree species are predominantly in line with the recommendations of the two Federal States.

In **Bavaria**, tree species recommendations are published for each forest disctrict *"Wuchsbezirk"* in a web portal called "Digitaler Baumexperte" (Bayerische Forstverwaltung, 2023). Recommendations are based on guidelines for selecting tree species suitable for a climate-resilient future forest state (Bayerische Forstverwaltung, 2020) and "Praxishilfe Klima - Boden - Baumartenwahl" (Bayerische Landesanstalt für Wald und Forstwirtschaft, 2019). For the forest district *Schwäbische Riesalb*, spruce is assessed with a very high risk and should, where it naturally occurs, be enriched by planting mixed tree species (which corresponds to the project activities). Silver fir is also assessed with a high risk (for 2100), but is still recommended as a suitable tree species to make up the mixture in the establishment of a new stand. All other species (oak, birch, beech, hornbeam, maple lime) are assessed with a low to very low risk and can therefore be considered suitable.

In **Baden-Württemberg**, tree species recommendations are published by FVA Baden Württemberg (2021) per forest district *"Wuchsbezirk"*. The recommendations further differentiate between regional site units (clustered by water balance, soil specifications, ...). The keys to determine the site units present on the project area are derived from the site mapping (*"Standortskartierung"*). The stands in

Baden-Württemberg lie in 2 site clusters: a) *Waldentwicklungstypregion 4.2 - Neckarland Submontan, Regionalzonale Einheit 4/21 Vorland der Ostalb* and b) *Waldentwicklungstypregion 6 - Schwäbische Alb, Regionalzonale Einheit 6/02 Submontan Mittlere Ostalb*. In a), for the site keys present on the project area (mainly wfTL and TL), most tree species are classified as possible or less suitable; but none are specifically excluded (unsuitable). Birch is not listed in these recommendations, but naturally occurs on the area and can be promoted as part of the future species mix. In b), for the site keys present on the project area (mainly wfTL), non of the tree species that make up the future species mix is classified unsuitable. Fir and birch are not listed, but birch occurs naturally on the area and fir has already been successfully seeded in district 21 and develops well in the project area.

The targeted tree species composition is promoted by mixture regulation and young growth maintenance. Accordingly, the diversity as well as the climate resilience of the stands is increased.

Hunting is intensified in the GHG project scenario. Promoting natural rejuvenation requires reducing the game population and optimizing its age structure and sex ratios (Fuchs, Vacek, Vacek, & Gallo, 2021). Another study indicates that large-scale wildlife management has the potential to effectively reduce browsing damage in Germany. The game-browsing could be reduced within three (3) years, by up to 50% (Hothorn & Müller, 2010). Due to intensive hunting we assume that in the long run about 61% instead of 22% of all regeneration plants survive (Hothorn & Müller, 2010).

6 Identifying GHG SSRs relevant to the baseline scenario

Cf. DIN EN ISO 14064-2:2019 Chapter 6.5

The GHG SSRs relevant for the GHG baseline correspond to those described in Chapter 4.

7 Selecting GHG SSRs for monitoring or estimating GHG emissions and removals

Cf. DIN EN ISO 14064-2:2019 Chapter 6.6

The GHG SSRs relevant for monitoring correspond to those described in Chapter 4.

8 Quantifying GHG emissions and/or removals and quantifying GHG emission reductions and removal enhancements

Cf. DIN EN ISO 14064-2:2019 Chapter 6.7 and 6.8

8.1 Generation of the Digital Twin

To model forest development with planned management prescriptions, a digital twin of the forest at the start of the project is used as input for the forest simulation (cf. Chapter 8.2). The final result of the digital stand generation is a database with all trees and their most important characteristics, such as height, dbh, age and tree species.

The data basis for the digital stand generation is the sample data based on circle plots from the forest inventory. Only the sample points which are located in the project area were used. The volume based standard error of this inventory is 7.56% (cf. Chapter 10). The sampling radii are 6m for all trees 7cm dbh and larger and 13m for all trees 30cm dbh and larger. For each tree, the dbh is measured and its tree species is determined. Height will only be measured on approximately five (5) trees of the various Kraft's classes. Missing heights are filled in during post-processing using a height curve function as a function of the measured dbh. Each sample represents a certain area in ha. This number is calculated by assessing how much area of the project is represented by the plot, based on previously stratified stands.

In the digital stand generation, a representative stand is generated for each actual stand. These are later simulated in the forest simulation as an independent unit, which allows to define different management strategies per stand. For example, a young spruce stand is treated differently than an old beech stand. The digital stand generation performs the following steps:

1. The trees are assigned to a sample by ID. After that for each group
    a. the trees of each sample point are divided into further groups depending on tree species and age class, e.g. spruce age class 4 (grouping in 20-year intervals),
    b. the number of trees in the entire stand is calculated based on tree density (the number of trees per sampling circle composing the representative area of the stand).
    c. Each tree is assigned a height and dbh according to the distribution from step b). The determination is done by sampling from the normal distribution based on the measurement list. First, the standard deviation of the tree species group on a stand is determined. In tree species groups with many trees, there may be isolated outliers, but these are not significant due to the high number of data points. For tree species groups with few trees, the outliers have a large influence on the calculated standard deviation. To circumvent the statistical disadvantage of small sampling sizes, the standard deviation is constrained as follows. For small groups with less than five (5) trees, a standard deviation of 25% is assumed for height and dbh. This avoids a large deviation due to small sampling sizes.
2. Each tree is written into the database. The position of the trees is selected pseudo-randomly to distribute the trees evenly, but still with varying distances.

3. Other tree parameters, such as crown height, are automatically filled in via completion routines for missing values in TreeGrOSS. The site index per tree is taken from the inventory. If no site index value is given, then the average site index in the project area is assumed (if enough data is available). If not, the default setting from TreeGrOSS is used (corresponds to a site quality index of 2).

The final result of the digital stand generation is a database with all trees and their most important characteristics, such as position, height, dbh, age and tree species.

8.2 TreeGrOSS Forest Simulation

In order to assess the development of the forest and GHG emissions based on the digital twin (cf. Chapter 8.1) over the GHG project duration, functions are used to simulate forest growth and to map forestry interventions. For this project, the Tree Growth Open Source Software (TreeGrOSS) software library developed by the Northwest German Forest Research Institute (NW-VWA) is used in combination with the associated software packages (Nordwestdeutsche Forstliche Versuchsanstalt, 2022). The software package was primarily developed for the BWINPro or ForestSimulator simulation software. This is used to simulate growth and treatments of individual samples or stands. Originally developed for northwestern Germany, the software has been extended and exemplarily re-parameterized in the course of various research projects for Brandenburg (Degenhardt, 2007), Saxony (Schröder, 2004) and Baden-Württemberg (Albrecht, Kohnle, & Nagel, 2011). These projects were able to show that the adjustments of growth parameters can lead to significant deviations in diameter and growth of individual modeled trees (Degenhardt, 2007; Schröder, 2004; Albrecht, Kohnle, & Nagel, 2011). For the parameters diameter ("Dg") and height ("Hg"), which are relevant for the calculation of aboveground biomass, the average deviation in the study on Baden-Württemberg was -4% (Dg) and -3.2% (Hg) (Albrecht, Kohnle, & Nagel, 2011). Moreover, if whole forest areas with a high number of samples or stands are considered (and thus hundreds of thousands of trees are simulated), and two simulations are compared to each other, these deviations are no longer detectable. In addition, to compensate for the random effects in the growth and mortality algorithms, a Monte Carlo simulation with 10 to 100 times repetitions is performed. The average values of these simulation runs are then used for further quantification steps. Therefore, TreeGrOSS is applicable without a new parameterization for the this project. The basic functions related to growth, mortality, and management are described below (Hansen & Nagel, 2014). The parameters used in the functions are listed in Chapter 11.4 and are subject to continuous monitoring. An overview of all formulas can be found in Annex 15.4. In addition, in Annex 15.5, a highly simplified Excel model illustrates the basic procedure of the forest simulation exemplarily.

Mortality

TreeGrOSS takes into account both density-related and climate-related mortality. “Whether a tree dies due to too high density depends on the minimum stand space requirement of the species. The minimum stand space requirement is determined using the functions of Döbbeler (Döbbeler, 2004) for maximum density estimation in conjunction with the crown width functions.” (Nordwestdeutsche Forstliche Versuchsanstalt, 2022).

Whether a tree dies due to climate depends on various factors. Survival models developed by Brandl et al. (Brandl, Paul, Knoke, & Falk, 2020), which are based on data from regional climate models of the Potsdam Institute for Climate Impact Research PIK e.V. (Potsdam-Institut für Klimafolgenforschung (PIK) are used to determine the climate-induced mortality probability.

The input parameters of the survival models are as follows:

- Tree parameters: Tree species, age, and share of mixture on the stand.
- Climate parameters:
  - Temperature: minimum, maximum, average for each quarter and the whole year
  - Precipitation: minimum, maximum, average for each quarter and the whole year.

Application of the survival models results in the 5-year climatic survival probability for each tree at each time reference point (variable $\hat{S}_{5,Klima}$) which is stored in the model.

For each simulation step it is compared whether the value $\hat{S}_{5,Klima}$ is greater than a random number between 1 and 0. If it is greater, the tree survives, if not, it dies. The following example explains the procedure. For each tree, a random number between zero (0) and one (1) is drawn, e.g. 0.3. Then it is determined whether the 5-year survival probability $\hat{S}_{5,Klima}$ (e.g. 0.5 or 50%) is greater or less than the random number 0.3. In this case, 0.5 is greater than 0.3 and the tree survives. If the 5-year survival probability $\hat{S}_{5,Klima}$ is 0.2, then the tree dies. Since there are more than 100,000 trees involved, the distribution of trees that die will equalize with the survival probability (law of large numbers).

The functionality for climate-induced mortality is not included in TreeGrOSS, but has been added to the program code by Pina Technologies GmbH.

Growth simulation

The growth model underlying TreeGrOSS is a statistical model in which each individual tree in a stand is described in its development. “This so-called single tree approach makes it possible to simulate almost any stand structure and composition. In this approach, tree growth is strongly abstracted and reduced to dbh and height increment. The functions for the increment estimation were parameterized tree species by tree species on the basis of experimental plot data. The variables used to influence increment are age, crown mantle area, crown competition index and its change with thinning” (Nordwestdeutsche Forstliche Versuchsanstalt, 2022). Thus, not only pure stands but also more structurally rich mixed stands can be simulated. In addition, the site index describes environment-specific growth factors, such as soil properties, climate, etc.. This is initially calculated for existing trees by TreeGrOSS using the ratio of tree height to age. Planted or rejuvenated trees inherit the site index. Thus, even without available data on soil conditions and climate, a distinction can be made to the environmental growth factors. “Mixed stand effects are realized in the model via the specific stand space requirements of the tree species, which are mainly derived from crown size. Crown size is calculated in the model from height, position of crown, and crown width for an assumed paraboloid, and the crown information needed for crown mantle area and crown competition index is estimated via static functions from breast height diameter, height, and stand top height" (Nordwestdeutsche Forstliche Versuchsanstalt, 2022).

The crown competition index (C66) "of an individual tree is defined as the sum of the crown cover areas of all trees in the stand that result when the crowns are cut at a height of two-thirds the crown length of the central tree (ks66). If the crown base of a tree is above the cutting height, the full crown cover area is considered. If the tree is smaller than the cutting height, it is not considered. The sum of the individual canopy areas thus determined at a given cutting height is related to the total area (A) of the stand" (Münder, 2005).

The site index describes the top height at age 100 in meters and is further dependent on the tree species (Hansen & Nagel, 2014). Formulas to compute the site index are presented in Annex 15.5.

Natural Rejuvenation

The plug-in to simulate ingrowth was created for this methodology and thus deviates from the original TreeGroSS software package. Simulation follows the following procedure:

Analogue to the existing TreeGrOSS model, the entire stand is divided into "regeneration cells" of 500m^2. For each cell it is determined how much space remains for trees to grow (by subtracting the sum of the base area of all trees taller than 1.3m and the crown area of all other trees from the 500m^2). Ingrowth placeholders are then placed in the remaining free areas in the cell. Number and species distribution of the placeholders are determined as follows:

1. Tree species composition is applied by randomly selecting from a weighted set of tree species. The weights are determined as follows:
    a. 50% from local ingrowth: Tree species are weighted according to the current species distribution within the regeneration cell.
    b. 50% from distant ingrowth: The basis for this is the species distribution (by crown area) over the entire forest area. For the final weighting, this is factored by the regeneration potential (ecological potency of Central European tree species) taken from Otto (1994).
2. The maximum number of ingrowing trees is determined by checking how many regeneration placeholders fit into the area. This is done by dividing the remaining available area from above by 2.52m^2 (the standardized crown width of a regeneration placeholder for a representative rejuvenated tree after 5 years). The number of ingrowing trees is then reduced by the following parameters:
    a. **Competition**: The more trees in the regeneration area, the less light is available for the ingrowing trees. A high competition value has a different effect depending on the shade tolerance of the ingrowing tree species. Shade-tolerant trees are hardly affected, while light-demanding trees will not grow if the competition is too high. In the simulation, this is taken into account as follows:

i. The crown competition index C66 (cf. TreeGrOSS) of the regeneration cell is calculated: Sum of the crown area of the trees on the plot, divided by the available area.

ii. The shade tolerance of the existing tree species is determined according to Otto (in the value range 1-5)

iii. The remaining number of regeneration placeholders is calculated:

F3: $$N * 1 - c66 * (1 - T)$$

The variables are defined as follows:

- N = Number
- $c66$ = Crown Competition Index
- T = Tolerance factor taken from Otto (1994)

b. NV intensity factor: Wildlife damage preventive measures (first and foremost hunting) are critical to the number of regeneration plants. However, TreeGrOSS does not provide settings and inherent mechanisms for this. Therefore, a factor was introduced to realistically simulate the effect of game damage prevention on the survival probability of regeneration plants. Due to intensive hunting in the GHG project scenario, it is assumed that 61% of regeneration plants survive (Hothorn & Müller, 2010), while 22% is assumed in the GHG baseline with occasional hunting (without a hunting plan) (Fuchs, Vacek, Vacek, & Gallo, 2021). These assumptions are based ex-ante on studies and expert opinion and will be verified by monitoring during the course of the project and adjusted if necessary. The result is a list of ingrowth placeholders (and assigned parameters by tree species) for each regeneration cell.

c. In order to represent the active promotion (or suppression) of certain tree species (forest management), this list is finally filtered according to the target tree species composition for the respective stand. The maximum share of ingrowth placeholders of one tree species is then equivalent to the maximum share in the target composition.

Before placing the ingrowth placeholders in the regeneration cell, their site index is calculated:

- If the tree species of the placeholder is already present in the stand, the average site index of this tree species is taken (including trees that have already been cut).
- If not, a default value per tree species group is chosen, corresponding to a credit rating of 2 (conservative assumption)

The placeholders are then positioned randomly within the regeneration cell.

Forest Management

The Silviculture software package associated with TreeGrOSS makes it possible to simulate diverse management activities, such as thinning, end-use, or planting (Hansen & Nagel, 2016). For this methodology, these functions were applied largely without change from the original TreeGrOSS software package.

To simulate planting, TreeGrOSS places young-tree-placeholders in the stands (analogous to the procedure for ingrowth). The simulation starts planting as soon as the stand falls below a previously defined crown coverage value. The number and tree species of placeholders depends on the target composition, the variable planting factor, and the current density in the stand. The planted tree placeholders are distributed randomly on the stand. After simulation, the number of placeholders is checked. A maximum of 2,000 placeholders per hectare may be used: 1ha / 5m^2 (area per placeholder).

The assumptions for end-use, thinning, planting, regeneration, and seeding differ depending on the GHG baseline (cf. Chapter 5.1) and GHG project scenario (cf. Chapter 5.2).

8.3 Quantification of GHG Emission Reductions and Removals

Total carbon of above-ground and below-ground living tree biomass for year t [CO_2] is calculated from the product of living tree biomass, biomass to carbon ratio, and carbon to CO_2 ratio.

F4: Forest CO_2 by estimate for the year t [CO_2]

$$CO2_{Forest,t} = LB_t * 0,5 * 3,667$$

The variables are defined as follows:

- LB_t = Living tree biomass for the year t [kg] (cf. Formula F5).
- 0.5 = Biomass to carbon ratio (Diestel & Weimar, 2014)
- 3.667 = Carbon to CO_2 by molar mass ratio

F5: live tree biomass for the year t [kg]

$$LB_t = \sum_{i}^{ntrees} B_{above,i} + \sum_{i}^{ntrees} B_{below,i}$$

The variables are defined as follows:

- $B_{above,i}$ = Above-ground biomass of tree i [kg] (cf. Formula F6).

- $B_{below,i}$ = Below-ground biomass of tree i [kg] (cf. Formula F7).

F6: Above-ground biomass of tree i [kg]

$$B_{above,i}$$

The calculations of above-ground biomass [kg] is performed according to the procedure of Riedel & Gerald (2016) based on the input parameters tree species, breast height diameter and tree height. These functions are currently used in German GHG reporting and are accepted by the IPCC (Riedel & Gerald, 2016). An implementation of these calculations is available as R library rBDAT (Vonderach, 2022). In order to apply comparable and transparent methods between the calculation of the above-ground and below-ground biomass, biomass functions based on peer-reviewed articles have been used since the 2015 submission. All selected biomass functions for calculating below-ground biomass conform to the following equation:

F7: below-ground biomass of tree i [kg]

$$B_{below,i} = b_0 d_i^{(b_1)}$$

The variables are defined as follows:

- $B_{below,i}$ = below-ground biomass of tree i
- d_i: dbh of tree i in cm
- b_0 und b_1 coefficients of below-ground biomass functions

8.4 Gross GHG emission reduction

The quantified GHG emission reductions for the year. [CO_2] is the sum of the difference in GHG reservoir in the forest of GHG project scenario and GHG baseline.

F8: Total gross quantified CO_2 reductions and removals for the year t [CO_2]

$$CO2_{gross,t} = (\Delta CO2_{project,forest,t} - \Delta CO2_{reference,forest,t})$$

The variables are defined as follows:

- $\Delta CO2_{project,forest,t}$ = Change in forest CO2 in the GHG project scenario, estimated for yr t [CO_2] (see Formula F4).
- $\Delta CO2_{reference,forest,t}$ = Change in forest CO2 in GHG baseline, estimated for yr t [CO_2] (see Formula F4).

8.5 Net GHG emission reduction

The net GHG emission reduction is the gross GHG emission reduction minus the risk buffer.

F9: Total net quantified CO_2 reductions and removals for the year t [CO_2]

$$CO2_{net,t} = CO2_{gross,t} - R_t$$

The variables are defined as follows:

- $CO2_{gross,t}$ = Total gross quantified CO_2 reduction and removal for the year t [CO_2] (cf. Formula F8)
- R_t = Risk buffer for the year t [CO_2] (cf. Formula F10)

The permanence of the certificates is secured, among other things, by a risk buffer shared by all GHG projects certified by Pina Technologies GmbH. Risk buffer describes a pool of certificates that is used as insurance for unavoidable losses in the projects and for ensuring the permanence of GHG emission reductions after the project period. Unavoidable loss describes a loss event caused by force majeure (including calamities from storms, bark beetles, or fire). Risk reserves are managed across all projects by Pina Technologies GmbH. The contribution to the buffer pool results from the sum of the risks (cf. Chapter 3.7) multiplied by the net GHG emission reduction (cf. Chapter 8.4). If the sum of the risks is <10%, it is rounded up to 10% for reasons of conservatism.

F10: risk buffer for the year t [%]

$$R_t = CO2_{gross,t} * (R_{nat,t} + R_{fin,t} + R_{mng,t} + R_{lon,t} + R_{pol,t})$$

The variables are defined as follows:

- $CO2_{gross,t}$ = Total gross quantified CO_2 reduction and removal for the year t [CO_2] (cf. Formula F8)
- R_{nat} = Natural risks for the year t [%]
- R_{fin} = Financial risks for the year t [%]
- R_{mng} = Project management risks for the year t [%]
- R_{lon} = Natural project longevity for the year t [%]
- R_{pol} = Political risks for the year t [%]

8.6 Number of carbon credits

The number of credits is calculated from the total quantified net GHG emissions reductions and removals over the project duration from year 0 to year 30. The issuance of the *ex-ante* credits follows the validation.

F11: Number of credits minus risk buffer worth one metric ton of CO_2 for year t

$$Z_{net,t} = \sum_{t=0}^{t=30} CO2_{net,t}$$

The variables are defined as follows:

- $CO2_{net,t}$ = Total net quantified CO_2 reduction and removal for the year t [CO_2] (cf. Formula F9)

8.7 Double counting

The GHG emissions and GHG emission reductions of the German forest are included in the German Greenhouse Gas Inventory. This forms the basis for Germany’s reporting to the European Union in relation to its Nationally Determined Contributions (NDCs) under the Paris Climate Agreement. As no “Corresponding Adjustments” are possible under Article 6.4 of the Paris Climate Agreement to date, any additional GHG emission reduction created by the GHG project is potentially counted twice. It follows that GHG emission reductions from this GHG project cannot be used to offset GHG emissions and claim climate neutrality. However, other claims, such as contributing to the achievement of German climate targets, are possible.

9 Additionality

The GHG project is to be registered only if it produces excess GHG emission reductions over and above what would have occurred in the absence of an emissions offset market (GHG baseline). The selection of dimensions of additionality that need to be reviewed, was modeled on the approach used by the Climate Action Reserve (Forest Protocol v5) (Climate Action Reserve, 2021) and the VCS for standardized methods (Verified Carbon Standard, 2013a). Accordingly, the GHG project was verified on legal (cf. Chapter 9.1) as well as performance-based additionality (cf. Chapter 9.2) and the financial feasibility of the scenarios was confirmed (cf. Chapter 9.3). In addition, the financial additionality of the GHG project is addressed.

9.1 Legal additionality

The GHG project is voluntary. This means that at the beginning of the project, the GHG project and the planned activities are not required by law. These include, but are not limited to, the Federal Forest and Nature Conservation Act of the Federal Republic (Bundesnaturschutzgesetz, 2009; Bundeswaldgesetz, 1975) and of the respective federal states. The project owner has also confirmed in the project contract that the implementation of the GHG project is voluntary. Thus, the project owner also confirms that they are aware of any legal regulations in the GHG project area, as well as special areas considered in the law (e.g. Natura 2000 protected area) (cf. Annex 15.1). Since the GHG Project emission reductions go beyond compliance with local, state, and federal laws, legal additionality is assured.

9.2 Performance-related additionality

For the purpose of verifying performance-based additionality, a performance-level (in terms of GHG reservoir) for business as usual is established for each project area. If the GHG project exceeds this performance level, it is classified as additional. Both the Verified Carbon Standard (Verified Carbon Standard, 2013a) as well as the Climate Action Reserve (Climate Action Reserve, 2021) recognize this methodology. In other words, project actions are considered additional if they result in GHG emission reductions beyond those that occur under a GHG reference scenario. For successful certification, the forest owner must demonstrate target-oriented action planning for the GHG project. The simulation of the GHG project scenario insists on these mandatory committed forest adaptation activities. The results of the quantification in Chapter 3.5 show that a higher emission reduction performance is achieved in the project scenario. This ensures the performance-based additionality of the GHG project.

9.3 Financial feasibility and additionality

The verification of financial additionality is not required by the applied procedures. Nevertheless, it was checked whether the GHG project scenario leads to higher costs or relatively lower profitability than it would have been the case in the GHG baseline.

Forest adaptation leads to increased costs due to the more complex removal procedures (e.g., motorized thinning or more protracted harvester operations to preserve natural rejuvenation), earlier and increased introduction of a wide variety of plants through extensive seeding, and intensified hunting (to promote natural rejuvenation).

At the same time, in both scenarios the forest is managed with the aim of wood production and thus timber is sold in both scenarios in an equivalent manner.

Since both the cost of the GHG project is higher and the revenue potential is similar than that of the GHG baseline, financial additionality is given.

10 Managing data quality

cf. DIN EN ISO 14064-2:2019 Chapter 6.9

Pina Technologies GmbH strives to maximize the accuracy of reference measurements and estimates of GHG reservoir through high quality data collection and processing procedures. This Chapter describes the quality management procedures implemented and applied to process data and information to identify and reduce uncertainties in the GHG baseline and project calculations.

The GHG project is based on high quality input data from German forestry surveys, by which the forest condition is recorded every ten years. In this GHG project, the standard error according to the forest inventory is 7.56% (cf. Annex 15.8), i.e. below the 10% (UNFCCC, 2015). The largest inaccuracies arise when extrapolating the number of trees in the permanent sample inventory to the entire stand, as only about 1% of the trees are surveyed at a usual sampling density of one plot. Terrestrial height measurements of trees have further deficiencies, as these are estimated based on elevation curves and common terrestrial measurement methods are more inaccurate than height measurements by LiDAR (Ganz & Käber, 2019). To counteract this, the number of trees on the plot and the individual tree heights are corrected using remote sensing data (cf. Chapter 11.3.2).

11 Monitoring the GHG project

cf. DIN EN ISO 14064-2:2019 Chapter 6.10

11.1 Purpose

The GHG Project will conduct monitoring activities in the form of data collection to monitor forest adaptation activities as well as GHG reservoirs on the GHG project area. In particular, the purpose of the monitoring is to examine the following:

- Successful execution of the tasks defined in Chapter 3.2 (cf. Chapter 11.2)
- Comparison of actual to estimated GHG reservoir in year 3, 6, 10, 15, 20, 25, and 30 based on remote sensing and inventory data (cf. Chapter 11.3)
- Improvement of ecological diversity (cf. Chapter 11.4)

After monitoring, all necessary steps will be taken to respond to the monitoring results. In addition, the data will be collected for future use in other similar GHG projects.

11.2 Monitoring of the project activities

The activities described in Chapter 3.2 must be implemented in order to achieve the predicted reduction and removal of GHG emissions through forest adaptation. For this reason, the activities and forest conditions will be reviewed and documented over the GHG project period. All activities, such as promoting natural rejuvenation by thinning the upper story or introducing new climate-resilient tree species through planting or seeding are documented. Therefore, monitoring draws on a range of different data. These include inventory data, data from photo documentation and evaluation, and remote sensing data.

In a first step, relevant data from the forest inventory, which is published every 10 years, is checked. It is controlled how the size of the rejuvenation areas develops over the course of the project.

In addition, the results of the project activities, such as thinning, sowing/planting and hunting, are documented and evaluated with the help of an app. This includes information on natural rejuvenation, sowing and planting, and game damage. To collect forest condition information, project owner, project implementers, foresters, Pina Earth or subcontractors take georeferenced photos in the 12 months prior to the monitoring date. Four photos must be taken at each site, as well as a 360 degree video. Natural rejuvenation and browsing must be documented at a minimum of one predefined sampling plot per stand. GPS inaccuracy may be +/- 15 meters. The project owner submits yearly hunting plans and estimates on game density per 100 hectare. Seeding and planting will be documented at the project site. After the photos are taken, additional information may be provided on a voluntary basis through a standardized questionnaire. Optional information on natural rejuvenation and browsing includes tree species distribution, height class proportions, frequency of browsing and peeling damage. Optional information on seeding and planting includes number of new trees and tree species distribution. This is followed by an evaluation by Pina Earth. Results are compared to the most recent rejuvenation status and assessed in the monitoring procedure. Improvement in terms of natural rejuvenation, seeding/planting, and browsing must be evident for the majority of the GHG project area. Refer to Annex 15.9 for more details on the planned app and associated monitoring approach.

The development of the upper story is monitored by remote sensing (cf. Chapter 11.3). A stronger thinning of the upper story, especially in the overstocked stands, should be clearly visible.

11.3 Monitoring GHG emissions and/or removals

11.3.1 Evaluation of remote sensing data

The quantification of the GHG reservoir is calculated for each monitoring following the procedure described in Chapter 8. The only difference is that Pina Technologies GmbH plans to base the digital twin (cf. Chapter 8.1) not only on inventory data, but also on remote sensing data. Individual tree detection and tree classification can be used to check how the upper story of the forest is developing. This includes identifying calamities caused by natural disasters, such as storms, or damages / forest loss as a result of deliberate disregard of the management plan by the project implementer, such as excessive use or clear-cutting. The data basis of the monitoring includes remote sensing data as well as inventory data:

- **Point cloud data**: Point cloud data are acquired and recorded by a special LiDAR (model Riegl VQ580) through an ultralight aircraft. Each point in a LiDAR data set has an X, Y, and Z value, as well as other attributes such as intensity. Aeromap GmbH collected the data on behalf of Pina Technologies GmbH.
- **RGBI image data**: The RGBI images are taken by a camera with a near-infrared sensor and have the three channels, red, green and blue, and a near-infrared channel. Aeromap GmbH collected the data on behalf of Pina Technologies GmbH.
- **Inventory Data**: Inventory data will be collected randomly across the GHG project area as part of the forest management process. At least every 10 years, the tree species, age structures, wood stocks and tree sizes such as dbh and tree height are recorded in a sample inventory procedure.

The digital twin of the forest is created in eight steps:

Step 1 – Canopy Height Model

In the first step, two data products are created based on the point cloud data: (1) the 'Digital Terrain Model' (DTM) determines the height of the surface, while (2) the 'Digital Surface Model' (DSM) represents the height of the highest surfaces for a given coordinate. The 'Canopy Height Model' (CHM) represents the difference between the (1) DTM and the (2) DSM. Accordingly, from the CHM the height of the trees can be determined (Wasser, 2022). Figure 5 shows a bird's eye view of a section of a representative GHG project area. The brighter a pixel is, the taller the tree is.

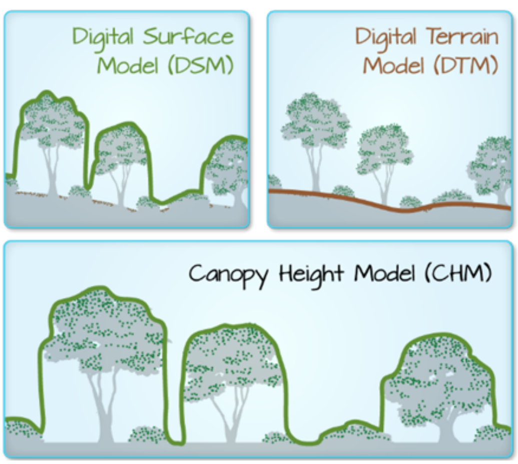

Figure 7: Canopy Height Model

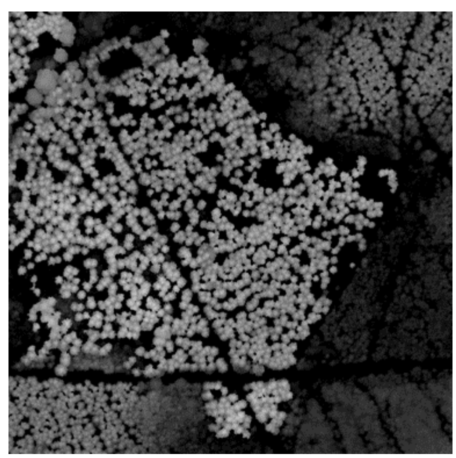

Figure 8: Section CHM from GHG project

Step 2 - Division into homogeneous divisions

In the second step, the entire GHG project area is divided into divisions. The aim is that the trees in this region are similar in terms of height, dbh, age and tree species or mixture of tree species. First, the GHG project area is divided into the divisions predefined by the forest owner in the forestry planning (cf. red boundaries in Figure 6, left). Since significant anomalies can often still be observed in these divisions, further subdivisions are defined. This step is done manually in QGIS, an open source geographic information system (QGIS, 2022). Based on the structural differences of trees that can be seen in the CHM, additional boundaries are defined (cf. green boundaries in Figure 6, right). In the following, these new subdivisions are referred to as stands.

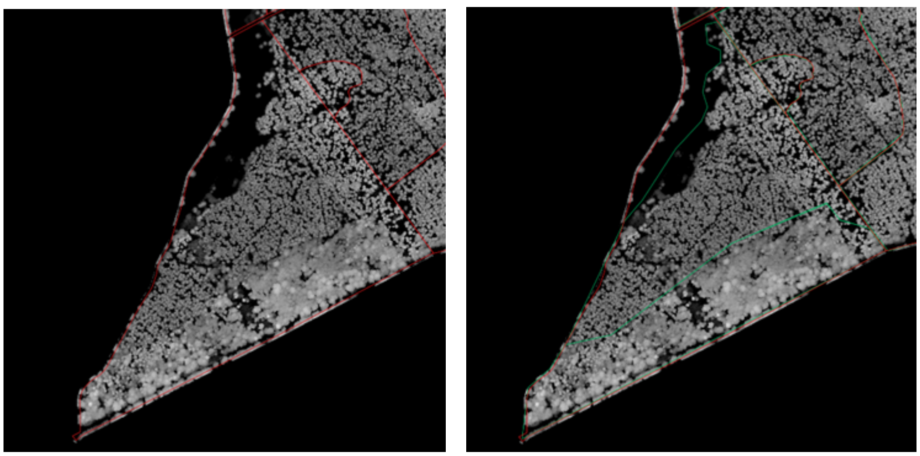

Figure 9: Section Divisions (left) and Subdivisions (right)

Both the CHM (cf. Figure 7, right) and the RGBI data (cf. Figure 7, left) are repartitioned based on these boundaries.

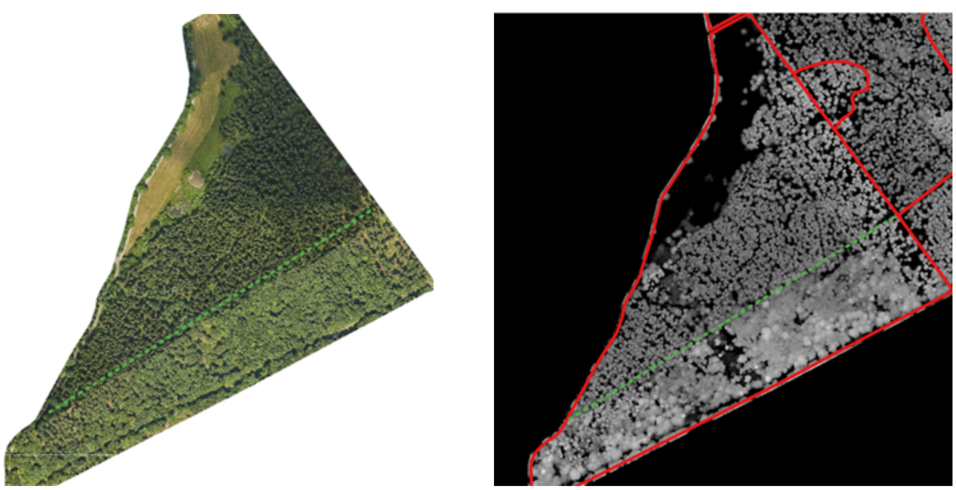

Figure 10: Section of subdivisions RGBI (left) and CHM (right)

Step 3 - Tree detection

In the third step, each tree and the shape of its canopy is identified based on the CHM. Only trees with a height ≥ 1.8 meters are considered, as the tree identification algorithm then achieves the highest accuracy. This threshold is set so that it has no impact on the GHG calculation, as trees below 1.8 meters in height have a dbh well below 7 cm and thus have no significant biomass. To generate the position of the tree tops (cf. Figure 8, left), the highest pixels in this stand are identified and all peaks in a height-dependent radius are ignored to avoid double detections ("local maxima"). Furthermore, the shape and area of the tree crown is defined adaptively, based on the height of the tree top and the maximum possible crown diameter of the tree (cf. Figure 8, right). This information is needed for the classification of the tree species in the following Chapters.

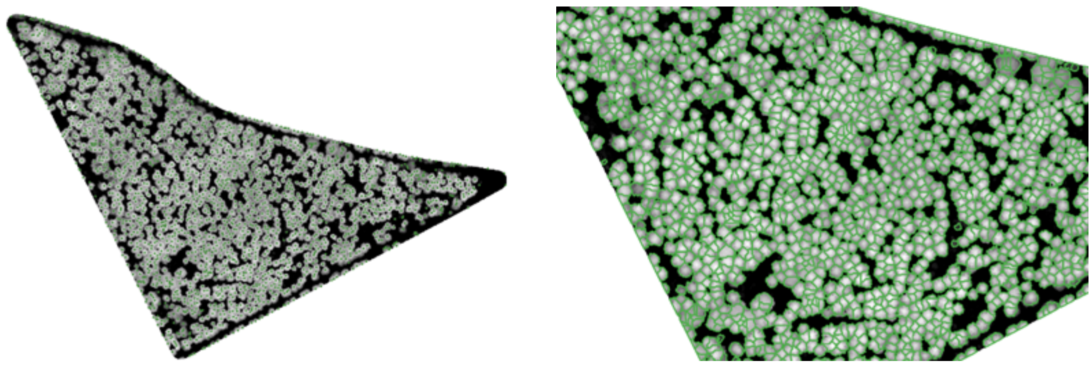

Figure 11: Section of tree tops CHM (left) and tree tops (right).

Step 4 - Classification of tree species

Classification of tree species into coniferous and deciduous is performed using an 'unsupervised learning' approach/algorithm, e.g., K-Means (Pedregosa, Varaquaux, Gramfort, & Michel, 2011), and thus follows other scientific approaches (Xu & et al., 2020). At this stage, no further tree species-specific discrimination is possible. However, the algorithm will be further developed in the coming years. This machine learning technique can detect patterns in unknown data by itself. In addition to the raw RGBI data, other features are extracted from the four channels of RGBI data with the goal of finding the smallest group of features that best reveals the natural classes of tree species. Since each tree canopy has a different shape (see 8.1.3), the features are aggregated for each individual tree canopy. The following features are included in the model: red, green, blue, and near-infrared channel, Enhanced Vegetation Index (EVI), Modified Soil Adjusted Vegetation Index (MSAVI), Green Normalized Difference Vegetation Index (GNDVI), Soil and Atmospherically Resistant Vegetation Index (SARVI), Atmospherically Resistant Vegetation Index (ARVI), Ratio Vegetation Index (RVI). (Xu & et al., 2020). Figure 9 shows that the classification algorithm detected two clusters, 70% conifers and 30% deciduous trees, for this section of the GHG project area.

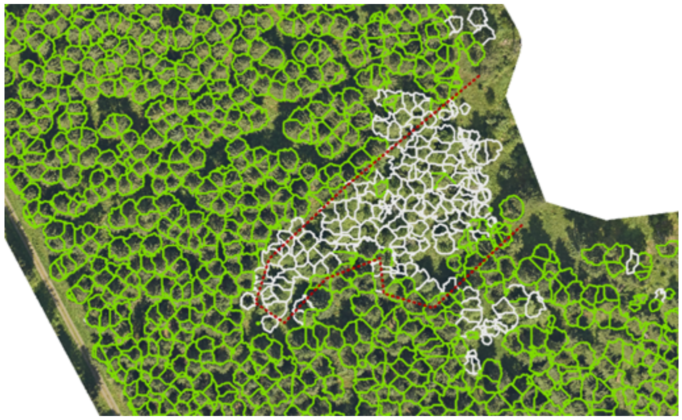

Figure 12: Section classification coniferous and deciduous tree species

Step 5 - Assignment of the trees

In this step, the trees previously detected by remote sensing (cf. red dots Figure 10) are compared with the random terrestrial inventory data (cf. blue dots Figure 10) to compensate for errors in GPS-based position measurement. This mapping is done using an algorithm based on a sliding window method and minimization of a cost function that takes into account the distance between trees and 'shifts' the blue dots to compensate for the terrestrial inventory position error. The end product is a 1-to-1 relationship between these trees.

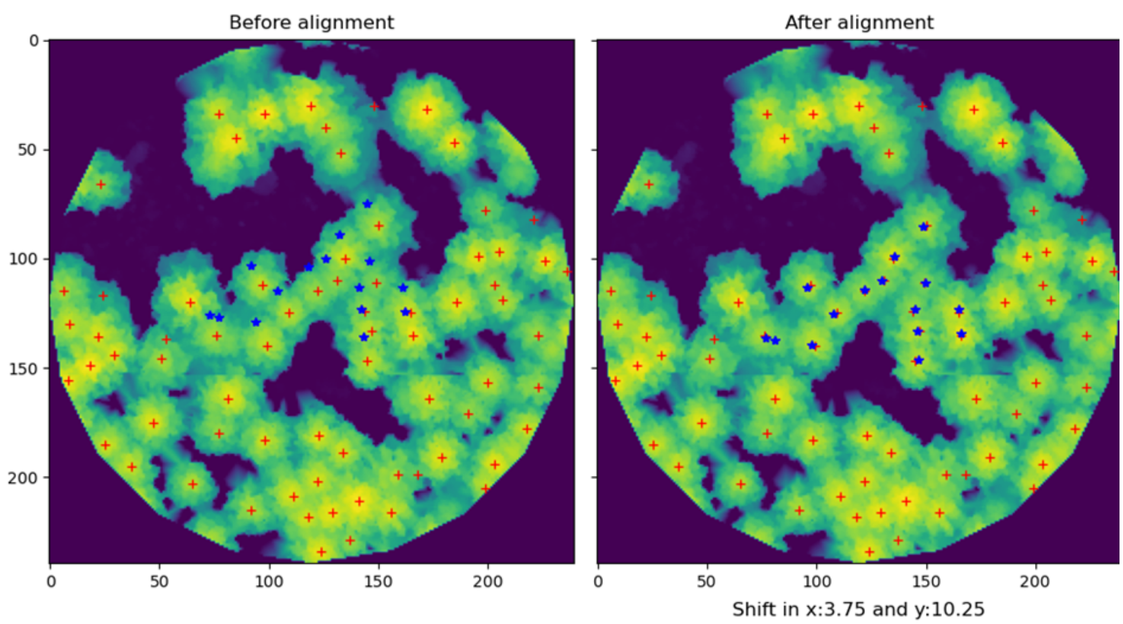

Figure 13: Detail allocation of remote sensing and inventory data

Step 6 - Quality control number of trees

For each stand, the quality of the tree detection (cf. step 3) is checked, since the algorithm does not provide sufficient results in all cases. In difficult cases, such as dense hardwood stands, the number of trunks may be overestimated. To compare the number of trees from the remote sensing data (cf. step 5) with the number of trees from the inventory data, two steps are necessary.

First, the location of the trees from both data sources in QGIS (QGIS, 2022) is visualized and their correspondence is manually checked. In the next step, the stem count, which is the number of trees per hectare, for each plot based on the remote sensing data is compared with the stem count from the inventory data. The deviation must not exceed +/- 10% to ensure the quality of the tree detection. Only then the trunk count of the algorithm is trusted. The stem count is a measure of tree cover based on the number of trees per unit area. It can also be interpreted as the degree of compaction within the stocked areas. Similar to the procedure in the inventory data, the stem count from the remote sensing data is calculated as follows: A tree is selected that is closest to the center of the inventory data sample. Based on the number of trees in a radius of 20 meters, the trunk number is calculated.

F12: calculation of number of trunks in plot p [number of trees per hectare]

$$S_p = \frac{n_p}{\pi * (20_m)^2} * 10.000m^2$$

The variables are defined as follows:

- n_p = number of trees in plot

Step 7 - Inventory overview

Then, a survey is created for each stand on the GHG project plot, which receives the following information:

- ID of the stock (cf. step 2) and the assigned plots based on inventory data (stocks without plot are assigned the most similar neighboring stock and the plots contained therein by manual inspection of the CHM).
- Mixture of tree species based on remote sensing data (see step 4).
- Number of trees based on inventory data.
- Number of trees based on remote sensing data (see step 5).
- Confidence marker for the number of stems of the remote sensing data (cf. step 6).

Step 8 - Digital stand generation

The digital stand generation generates the final trees for the entire GHG project area, which then in the next step provide the input data for the TreeGrOSS forest simulator (cf. Chapter 8.2). The digital stand generation performs the following steps for each stand on the GHG project area:

1. The number of trees, individual tree heights, and mixture of tree species of the random inventory data are corrected using the results from remote sensing (see Step 7).
2. The trees from the inventory data are assigned to a group according to tree species and age class (grouping in 20-year intervals), e.g. spruce age class 4. For each group, the following is calculated
    a. the number of trees in the entire stand based on the tree density of the corrected inventory data.
    b. the distribution of tree heights and dbh based on the corrected inventory data using a normal distribution.
    c. Each tree is assigned a height and dbh according to the distribution from step b). The determination is done by sampling from the normal distribution based on the measurement list (“Kluppliste”). For small groups with less than 5 trees, a standard deviation of 25% is assumed for height and dbh to avoid large deviations due to small sampling sizes.
3. Each tree from each group is written into the database with the following characteristics: Tree species, age, height and dbh. The position of the trees is selected pseudo-randomly. Other values, such as crown height, are automatically filled in via completion routines for missing values in TreeGrOSS.

11.3.2 Monitoring of actual GHG reservoir

In the data described in Chapter 11.1 the actual GHG reservoir on the project area is documented using current inventory and remote sensing data, depending on the conditions. Subsequently, this will be compared with the forecast from Chapter 8. For this purpose, the following temporally fixed and variable data are collected. The monitoring methodology is described in Chapter 8 as well as in Chapter 11.3.1 explained.

Variable parameters

The variable parameters needed to monitor the GHG reservoir originate from data collected continuously at the project site. They are subject to change over the project period and are therefore included in the data described in Chapter 11.1 above and will be reviewed at the intervals specified in this chapter. The parameters to be reviewed will fall both within the creation of the digital twin (cf. Chapter 8.1), during the forest simulation (cf. Chapter 8.2) as well as in the quantification of the GHG reservoir (cf. Chapter 8.3).

The variable parameters to be monitored in the creation of the digital twin can either be taken directly from the forest inventory data or are based on remote sensing data and are the following:

Parameter	**Number of trees per stand**
Data unit	Quantity
Description	Number of trees per stand

Source	Sampling data from the forestry inventory or remote sensing
Description of the measurement methods and procedures to be used	Sampling data from the forestry inventory (plot-based sampling), generated on the basis of remote sensing data (cf. Chapter 11.3.1)
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	Carrying out a plot-based inventory in future monitoring cycles
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	**dbh of the trees**
Data unit	Centimeter
Description	Diameter at breast height measured or assigned for each tree in the project area.
Source	Sampling data from the forestry inventory
Description of the measurement methods and procedures to be used	The data originate from the respective current forest inventory (see calculation method in Chapter 8.1) and are generated on the basis of remote sensing data (cf. Chapter 11.3.1)
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The high-quality data come from the forestry inventory (cf. Chapter 10)
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	**Tree species**
Data unit	Name
Description	Tree species, measured or assigned for each tree in the project area.
Source	Sampling data from the forestry inventory
Description of the measurement methods and procedures to be used	The data originate from the respective current forest inventory (see recording instructions in Annex 15.1) and are generated on the basis of remote sensing data (cf. Chapter 11.3.1)
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The high-quality data come from the forestry survinventory (cf. Chapter 10)
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	**Age of the trees**
Data unit	Years
Description	Age, measured or assigned for each tree in the project area.
Source	Sampling data from the forestry inventory
Description of the measurement methods and procedures to be used	The data originate from the respective current forest inventory (see Chapter 8.1) and are generated on the basis of remote sensing data (cf. Chapter 11.3.1)
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The high-quality data come from the forest inventory (cf. Chapter 10)
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	**Tree height**
Data unit	Centimeter
Description	Height, measured or assigned for each tree in the project area.
Source	Sampling data from the forestry inventory
Description of the measurement methods and procedures to be used	The data originate from the respective current forest inventory (see calculation method in Chapter 8.1) and are generated on the basis of remote sensing data (cf. Chapter 11.3.1)
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The high quality data comes from the forest inventory (cf. Chapter 10)
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	**Crown width**
Data unit	Centimeter
Description	Crown width indicates the diameter of a tree crown. It can be measured directly on the segmented tree crown from remote sensing data.
Source	Remote sensing data
Value used	Tree dependent

Justification for the selection of data or description of the measurement methods and procedures used.	Determination of crown width from remote sensing data is more accurate and time-saving compared to determination from terrestrial data and is therefore used.
Intended use of the data	Needed to map a realistic inventory

Parameter	**Unit Height Curve**
Data unit	Uniform
Description	Determination of the general relationship between tree diameters and heights of a tree species in the form of a parabola.
Source	Forest Management
Value used	-
Justification for the selection of data or description of the measurement methods and procedures used.	-
Intended use of the data	Needed to map a realistic inventory

Parameter	**Diameter generation/regression**
Data unit	Uniform
Description	Method in which tree canopy values (obtained from remote sensing data) are used to determine the diameter of each tree by species-specific regression
Source	Proprietary method inspired by (Yang et al., 2020).
Value used	-
Justification for the selection of data or description of the measurement methods and procedures used.	Diameter cannot be measured directly from remote sensing data, so it is determined indirectly via the crown parameters
Intended use of the data	Needed to map a realistic inventory

Fixed parameters

The fixed parameters needed to monitor the GHG reservoir do not originate from data collected at the project site. The fixed parameters are used both during the creation of the digital twin (cf. Chapter 8.1), in the forest simulation (cf. Chapter 8.2) as well as in the quantification of the GHG reservoir (cf. Chapter 8.3) and have already been mentioned in these Chapters.

The fixed parameters involved in forest simulation come from TreeGrOSS or are assumptions based on scientific sources. The parameters are the following:

Parameter	**Potential height growth function**
Data unit	Uniform
Description	Indicates the potential height growth of each tree in the project area
Source	Formulas TreeGrOSS
Description of the measurement methods and procedures to be used	Extraction of the data from the formulas of the TreeGrOSS
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The underlying TreeGrOSS growth model is a nationally recognized statistical model. The latest version of the TreeGrOSS is always used
Intended use of the data	Used to calculate the growth of individual trees

Parameter	**Diameter increment function**
Data unit	Uniform
Description	Indicates the potential diameter increment of each tree in the project area
Source	Formulas TreeGrOSS
Description of the measurement methods and procedures to be used	Extraction of the data from the formulas of TreeGrOSS (cf. Annex 15.4)
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The underlying TreeGrOSS growth model is a nationally recognized statistical model. The latest version of the TreeGrOSS is always used
Intended use of the data	Used to calculate the growth of individual trees

Parameter	**Volume function**
Data unit	Cubic meters
Description	Species-specific volume function that TreeGrOSS uses to calculate volume as a function of tree height and diameter.
Source	TreeGrOSS formulas (cf. Annex 15.4)
Value used	Defined per species (cf. Annex 15.4)
Justification for the selection of data or description of the measurement methods and procedures used.	TreeGrOSS is a widely used forest growth simulator in Germany, which assigns its specially adapted volume formula to each tree species
Intended use of the data	Needed to map a realistic inventory

Parameter	**Crown width function**
Data unit	Uniform
Description	Crown width specifies the diameter of a tree crown. The function is used to calculate the crown width from the dbh of a tree.
Source	TreeGrOSS formulas (cf. Annex 15.4)
Value used	Defined per species (cf. Annex 15.4)
Justification for the selection of data or description of the measurement methods and procedures used.	If no remote sensing data is available, or the tree detection is not accurate enough, the crown widths of the trees of the digital twin are calculated based on the dbh.
Intended use of the data	Needed to map a realistic inventory

Parameter	**Crown height Function**
Data unit	Uniform
Description	Height above the ground from which the crown of the tree begins
Source	TreeGrOSS formulas (cf. Annex 15.4)
Value used	Defined per species (cf. Annex 15.4)
Justification for the selection of data or description of the measurement methods and procedures used.	Due to the high effort involved, the crown height is neither recorded in the forestry planning nor by remote sensing data. To calculate this, species-specific formulas based on the height and the dbh of a tree are used.
Intended use of the data	Used to accurately determine diameter growth (see Annex 15.4).

Parameter	**Site Index Function**
Data unit	Uniform
Description	Formula for calculating the top height bonus from the height of the 100 tallest trees and the tree age
Source	TreeGrOSS formulas (cf. Annex 15.4)
Value used	species-dependent
Justification for the selection of data or description of the measurement methods and procedures used.	TreeGrOSS is a widely used forest growth simulator in Germany that assigns a specially adapted site index to each tree species
Intended use of the data	Used to accurately determine height growth (see Annex 15.4).

Parameter	**Site Index Height Function**
Data unit	Uniform
Description	Modified formula of the site index for the calculation used for the calculation of youth growth.
Source	TreeGrOSS formulas (cf. Annex 15.4)
Value used	species-dependent
Justification for the selection of data or description of the measurement methods and procedures used.	TreeGrOSS is a widely used forest growth simulator in Germany that assigns a specially adapted Site Index Height to each tree species
Intended use of the data	Used to accurately determine the height growth (cf. Annex 15.4) of young trees with a trunk diameter < 7cm or tree height <1.3m

Parameter	**Maximum tree density function**
Data unit	Uniform
Description	Formula for calculating the maximum stem number density of a stand as a function of tree heights
Source	TreeGrOSS formulas (cf. Annex 15.4)
Value used	species-dependent
Justification for the selection of data or description of the measurement methods and procedures used.	TreeGrOSS is a widely used forest growth simulator in Germany, which calculates a maximum stem number density for each stand
Intended use of the data	The Maximum Tree Density is used to calculate the thinning volume and it feeds into the calculation of competition mortality, which causes trees to die when the density is too high.

Parameter	**Climate-related mortality**
Data unit	Number between 0 and 1
Description	Based on climatic conditions at the site, climate-related mortality indicates the 5-year survival probability for each tree in the project area

Source	Survival time models according to Brandl (Brandl, Paul, Knoke, & Falk, 2020) and data from regional climate models by PIK e.V. (Potsdam-Institut für Klimafolgenforschung (PIK) e. V., 2022)
Description of the measurement methods and procedures to be used	Extraction of data from the regional climate models of PIK e.V.
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The calculation of climate-related mortality is always based on current data and the latest scientific findings
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	**Proportion of surviving regeneration plants Reference scenario**
Data unit	Percent
Description	Proportion of surviving regeneration plants in the reference scenario.
Source	(Fuchs, Vacek, Vacek, & Gallo, 2021)
Description of the measurement methods and procedures to be used	Extraction of data from the latest scientific findings
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The assumptions made for the proportion of regeneration plants surviving in the reference scenario are based on the latest scientific findings
Intended use of the data	Needed to calculate GHG reservoir in the reference scenario.

Parameter	**Proportion of surviving regeneration plants Project scenario**
Data unit	Percent
Description	Proportion of surviving regeneration plants in the project scenario.
Source	(Hothorn & Müller, 2010)
Description of the measurement methods and procedures to be used	Extraction of data from the latest scientific findings
Monitoring frequency	In year 3, 6, 10, 15, 20, 25 and 30
QA/QC procedures to be applied	The assumptions made for the proportion of regeneration plants surviving in the project scenario are based on the latest scientific findings

Intended use of the data	Needed to calculate GHG reservoir in the project scenario.

The fixed parameters to be reviewed in quantifying GHG reservoir are the same as those used in German GHG reporting and accepted by the IPCC. The parameters are the following:

Parameter	**Biomass to carbon ratio**
Data unit	Percent
Description	Defines the proportion of carbon in the wood biomass
Source	(Diestel & Weimar, 2014)
Value used	50%
Justification for the selection of data or description of the measurement methods and procedures used.	Generally accepted value for converting biomass to carbon
Intended use of the data	Required for the calculation of CO_2 storage capacity

Parameter	**Carbon to CO_2 by molar mass ratio**
Data unit	-
Description	Defines the ratio of the mass of CO_2 to pure carbon
Source	-
Value used	3,667
Justification for the selection of data or description of the measurement methods and procedures used.	-
Intended use of the data	Required for the calculation of CO_2 storage capacity

Parameter	**Above-ground biomass from tree**
Data unit	Kilogram
Description	Defines how much biomass is present above-ground in the tree and results from the compact wood biomass and the branch wood biomass.
Source	(Riedel & Gerald, 2016)
Value used	Tree dependent
Justification for the selection of data or description of the measurement methods and procedures used.	Generally accepted value for the calculation of above-ground biomass

Intended use of the data	Required for the calculation of CO_2 storage capacity

Parameter	**Below-ground biomass from tree**
Data unit	Kilogram
Description	Defines how much biomass is present below the ground in the tree and results from the roots
Source	(Umweltbundesamt, 2023)
Value used	Tree dependent
Justification for the selection of data or description of the measurement methods and procedures used.	Generally accepted value for the calculation of below-ground biomass
Intended use of the data	Required for the calculation of CO_2 storage capacity

11.4 Ecological Diversity Monitoring

In order to secure ecosystem services in the long term, it will be verified whether the project activities lead to a continuous improvement in the structural diversity and species diversity of the stands over the GHG project period. Species diversity is described by the Shannon-Wiener index and its evenness (Tremp, 2005; Dierschke, 1994; Lang, Tiede, Maier, & Blaschke, 2006). The Shannon-Wiener index is a measure to determine the diversity of different tree species within a stand. The minimum value is 0, meaning that the entire stand is assigned to one tree species. The larger the value, the more diverse the tree species in the stand and the more evenly distributed the tree species are.

F13: $$H^I = -\sum_{i=1}^{s} p_i * ln_{pi} \text{ with } pi = \frac{n_i}{N}$$

The variables are defined as follows:

- H^I = Shannon-Wiener index
- p = Total number of tree species
- n_i = Number of trees of one tree species
- N = Sum of all trees
- p_i = Relative proportion of tree species i between 0 and 1

In addition, the evenness represents the degree of equal distribution of tree species.

F14: $$E = \frac{H^I}{H_{max}} \text{ with } H_{max} = lns$$

The variables are defined as follows:

- E = Evenness
- H^I = Shannon-Wiener Index
- H_{max} = individual maximum diversity
- s = Total number of tree species

The structural indices are based on the single tree values of each stand, that is, each tree species per stand. These values are then averaged over all stands.

Simulation Step	Shannon-Index	Evenness
Year 0	0.42	0.45
Year 5	0.94	0.57
Year 10	1.16	0.64
Year 15	1.13	0.63
Year 20	1.12	0.63
Year 25	1.09	0.63
Year 30	1.09	0.63

Table 13: Shannon index and evenness of tree species.

After 30 years, there must also be a rejuvenation layer on the entire GHG project area. This is verified using the data in the forestry report in Annex 15.1.

11.5 Monitoring Roles and Responsibilities

The monitoring of the forest adaptation activities as well as the GHG reservoir is the responsibility of Pina Technologies GmbH. However, qualified parties can be contracted for the collection of remote sensing data, inventory data, and on-site inspections.

11.6 Information Management

Pina Technologies GmbH has developed an information management system to keep the data for each GHG project up to date. All documents, such as contracts, inventory data, and results reports, are backed up in the Google Drive cloud. The program code for calculating GHG storage capacity and their results are stored in separate repositories and in the Amazon Web Services Cloud. All data is kept for the duration of the GHG project, as long as Pina Technologies GmbH operates as a company.

12 Documenting the GHG project

cf. DIN EN ISO 14064-2:2019

The GHG project development will be documented according to the requirements of *DIN EN ISO 14064-2:2019 (see* *Chapter 11.6).*

13 Verification and/or validation of the GHG project

cf. DIN EN ISO 14064-2:2019 Chapter 6.12

This GHG project description was prepared for validation according to the ISO 14064-2 standard. The validation and initial verification is carried out by TÜV NORD CERT GmbH. A renewed verification is planned halfway through as well as at the end of the project period.

If any deviations from the initial projection of GHG emission reductions are found during the verification:

- in case of initial underestimation of GHG emission reduction, additional credits are issued
- In the event of an initial overestimation of the GHG emission reduction, credits are deducted from the risk buffer accordingly.

14 Reporting the GHG project

cf. DIN EN ISO 14064-2:2019 Chapter 6.13

Pina Earth is not required to provide reporting on the GHG project at this stage of the ISO 14064-2 certification process. As part of the regular monitoring of the GHG project, a report will be prepared in accordance with the requirements of ISO 14064-2, Chapter 5.13 and provided to the intended users.

15 Annex

#	Name	Format	Comments
15.1	Forest Inventory Data	pdf	
15.2a	GHG project contract	pdf	
15.2b	GHG project contract Anlage 5.2 - Mindeststandards	pdf	
15.2c	Project activities overview	pdf	
15.3	Natural risks	xlsx	a: Baden-Württemberg b: Bavaria
15.4	Formulas TreeGrOSS	xlsx	
15.5	Results GHG sink	xlsx	
15.6	Forest land maps (folder)	pdf	Excerpts per district
15.7	Monitoring concept app	pdf	
15.8	Forest Inventory Data Analysis	txt	
15.9	Methodology Documentation Pina Earth (DE)	pdf	In German
15.10	Expert Assessment on Methodology	pdf	In German
15.11	Evidence for project start date (Seed material invoice)	pdf	In German
15.12	Stock development and increment breakdown over project duration	xlsx	

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