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FOREST ADAPTATION PROJECT

LUCKAITZTAL

Type: Forest adaptation | Version: 0.4 | Issue date: 16.02.2023

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In case of any ambiguity or discrepancy, the German original will prevail.

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1. Background

The methodology for the Luckaitztal Forest Adaptation Project was primarily developed using the following standard: DIN EN ISO 14064-2 Greenhouse gases - Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas (GHG) emission reductions or removal enhancements, May 2020. (Deutsches Institut für Normung, 2020). In addition, a number of other best practice guidance documents were consulted, including general guidance on GHG quantification, specific guidance for forest GHG projects, and literature corresponding to the current state of the science. All sources are listed in the bibliography (Chapter 16).

2. Terms

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

Tree species proportions: Tree species proportions are the proportions of each tree species based on the canopy area of the associated trees.

Degree of Stocking: The degree of stocking refers to the mass stock of a stand and is expressed in tenths of the full stock.

Diameter at breast height (dbh): The breast height diameter is the diameter of a tree at a height of 1.3 meters.

CO_2 certificate: A CO_2 certificate describes one (1) ton of CO_2 reduction in GHG emissions and enhancement in GHG removal, measured in CO_2.

Cubic meter of timber harvested (Efm): The cubic meter of timber harvested corresponds to one cubic meter standing of stock minus bark losses and losses during harvesting.

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

Normal stock: Normal stock is a quantity measured in cubic meter standings of stock, which describes the target stock of a stand or a farm. The size is defined by a yield table for the respective tree species at given age intervals.

Measurement list: The measurement list includes all trees and their breast height diameter, height, age and tree species recorded during the sample inventory.

Canopy density: Canopy density is a measure of stand density, or the area occupied by trees in a forest.

Ongoing increment: Ongoing increment represents the annual increase in the forest stand resulting from the growth of trees.

Weeding: Weeding (thicket maintenance) is a stand regulation measure in forestry, a purely negative selection.

Low thinning: In low thinning, trees from the lower layers in particular are removed from the tree stand.

Project implementer: The project implementer is a third party contracted by the project owner to manage the forest land.

Project owner: The project owner is the owner of the forest area.

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

Litter overlay: Litter overlay is last year's freshly dead organic matter that rests on barely changed soil.

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

Cubic meter standing (Vfm): The cubic meter standing of stock indicates the wood stock of a standing tree.

Real stock: The real stock is a quantity measured in cubic meter standing, which describes the actual stock of a stand or a farm. The degree of stocking can be determined by comparison with the normal stock.

3. Describing the project

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

3.1. Objective

The Luckaitztal Forest Adaptation Project primarily pursues the goal of converting pure stands into bio-diverse and structurally diverse stands which:

- reduce climate-related risks,
- achieve a higher overall growth performance, and
- increase the stock density in the long term.

In addition, biodiversity and other ecosystem services in the forest are improved.

In sum, the GHG reservoir on the forested land is enhanced and therefore a voluntary contribution to climate protection is made.

3.2. Measures

This GHG project is an "Improved Forest Management" GHG project (cf. (Verified Carbon Standard, 2013b). Through forest adaptation measures, the areas in the GHG project are to be converted from endangered pure stands into stable multi-layered mixed stands. In this context, the measures are selected and implemented based on the needs of the stand. In particular, these are (cf. Annex. 15.1):

- Initial stock reduction through increased thinning and end-use to develop single-tree stability and allow new increments in lower layers; and
- Encourage and protect natural rejuvenation supplemented by planting and seeding native and climate-resilient tree species, such as oak, beech, and Douglas-fir, to increase structural and ecological diversity in the stand.

As a result, the areas see a densification of stands, increased overall growth, and a reduction in mortality culminating into a removal of 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 science, the most effective management measures can thus be selected.

The practical forest adaptation measures 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 measures can be divided into the categories logging and forest maintenance, young growth maintenance and thinning, planting and natural rejuvenation, and hunting.

Logging and forest maintenance

Logging and forest management ensures that high quality timber is harvested from the older stand layers while preparing them for new stand layers achieved by planting and natural rejuvenation. Through individual tree removal, the higher quality trees remain and their stability is increased. Additionally, after tree removal, space is made allowing for the planting of new young trees. Lastly, natural rejuvenation is promoted by thinning out the existing stand to create light and by maintaining the soil, especially by removing competing vegetation.

Young growth maintenance and thinning

In younger stands, the focus is on young growth management and thinning. Here, regular thinning and stem number separation will be used to reduce competitive. The desired proportions of tree species can be achieved by regulating the mixture. The desired tree species composition of the target condition should be determined according to the guidelines of Riek et al. (Riek, Russ, & Grüll, 2020) happen. Specifically, for each stand, the associated site cluster is determined using data from the Brandenburg Geoportal (Land Brandenburg, 2022). Each site cluster is then assigned a forest type, (forest type IIa) (Riek, Russ, & Grüll, 2020). Based on the forest type, tree species compositions are defined, outlining the target mixing ratio of each tree species. These ratios take into account the upper and lower limit proportions based on the tree species previously existing in the stand, as defined by Riek et al. (Riek, Russ, & Grüll, 2020). For example, if the target value for noble wood on the plot is 5% and there is 1% maple and 1% chestnut on the plot in the initial state, a target value of 2.5% is defined for both tree species.

The following tree species composition is targeted on the GHG project area: High-growth Douglas-fir and shade-tolerant fir, species well suited for forest adaptation, shall be preferred in stands where they can be planted. In addition, mixed tree species (mostly deciduous) should be promoted or introduced in each stand to increase biodiversity and climate resilience. If a deciduous tree species of a tree species group to be admixed is not previously present, a preferred tree species for the group will be used (e.g., birch, maple, linden, or hornbeam). A detailed overview of the selected tree species compositions (on a tree species and tree group basis) can be found in Table 1.

	Area share	Pine	Douglas fir	Fir	Oak	Beech	WLH	SHL
A1 and NA2-A1	8.5%	65%	5%	5%	10%	5%	5%	5%
M2	13.7%	50%	10%	10%	10%	10%	-	10%
K1w	1.3%	55%	10%	17.5%	10%	-	7.5%	-
Z2	70.5%	65%	7.5%	7.5%	5%	-	7.5%	7.5%
Z2g	6.0%	60%	12.5%	12.5%	5%	5%	-	-

Table 1: Tree species compositions in the target condition based on the site cluster.

Planting and natural rejuvenation

Planting and natural rejuvenation are intended to increase growth, introduce new tree species, and create multi-layered stands. The primary goal of planting is to introduce new tree species. Tree species selection is done through the tree species compositions mentioned in the previous paragraph. In the case of existing tree species, natural rejuvenation is to be encouraged and planting of existing tree species is to be avoided altogether.

Hunting

A key component to ensuring regeneration is intensified hunting. If game populations are not controlled, browsing and shearing damage will increase, significantly reducing the number of regeneration plants. Hunting is an important tool in the adaptation effort because the majority of the GHG sink comes from the under storey established through regeneration.

3.3. Location

The private forest district Luckaitztal is directly contiguous except for a few parts and is located west of the village Luckaitz in Brandenburg. The cadastral area is about 680 ha and covers the following municipalities: Bronkow, Gosda, Lipten, and Schöllnitz (Annex 15.1). A georeferenced shapefile of the project area in Figure 1 allows for clear identification and description of the specific extent of the GHG project.

Figure 1: Forest base map

3.4. Initial situation

The information on the baseline situation of the GHG project in the following Chapters is based on the forestry report of the Luckaitztal forestry company (cf. Annex 15.1).

Climate

The GHG project is 100% located in the climate stage Tm - lowland with a moderately dry climate. The average rainfall of 560 - 600 mm per year and the average annual temperature of about 8.5 °C characterize the moderately dry, already noticeably continental macroclimate. The altitude of the project area was determined to be approx. 110 – 145 m above sea level.

Soils

The soils are formed exclusively on sands of the glacial series (old moraine of the Saale cold period). Therefore, they are usually poorer sandy-brown soils or sandy-brown podsols, i.e. soils with poorer to medium nutritional properties.

Tree species distribution

The main tree species in the GHG project is pine with 92%. Other noteworthy tree species groups are: softwood (WLH; mainly birch, to a lesser extent also rowan), hardwood (SHL; mainly red oak and maple), coniferous (SNB) and oak (sessile oak). With its emergent conifer stands, it deviates in some cases significantly from the potential natural vegetation while the naturalness increases in the under storey due to the hardwood admixtures.

The tree species in the upper storey are composed as follows:

Tree species group	Pine	Spruce	Oak	SHL	WLH	Total
Wood floor area (ha)	584.6	1.0	12.9	6.9	27.0	632.40
Share (%)	92.45	0.15	2.04	1.09	4.27	100

Table 2: Tree species in the upper storey

The tree species in the under storey are composed as follows:

Tree species group	Spruce	SNB	Beech	SHL	WLH	Total
Wood floor area (ha)	3.83	0.16	5.73	26.13	150.16	186.01
Share (%)	2.1	0.1	3.1	14.0	80.7	100

Table 3: Tree species in the under storey

Age group ratio

The age group distribution in the upper storey is as follows:

	I	II	III	IV	V	VI	VII	VIII	IX	X	Total
Pine	57.46	69.35	160.67	185.12	30.06	46.65	32.10	3.24	0.00	0.00	584.64
Larch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spruce	0.00	0.00	0.71	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.97
SNB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oak	0.00	9.86	0.00	0.83	0.00	0.00	2.22	0.00	0.00	0.00	12.91
Beech	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHL	0.00	2.72	4.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.87
WHL	1.84	5.29	10.39	8.66	0.00	0.00	0.83	0.00	0.00	0.00	27.01
Total	59.30	87.22	175.92	194.87	30.06	46.65	35.15	3.24	0.00	0.00	632.40

Table 4: Age classes according to tree species in the upper storey by area

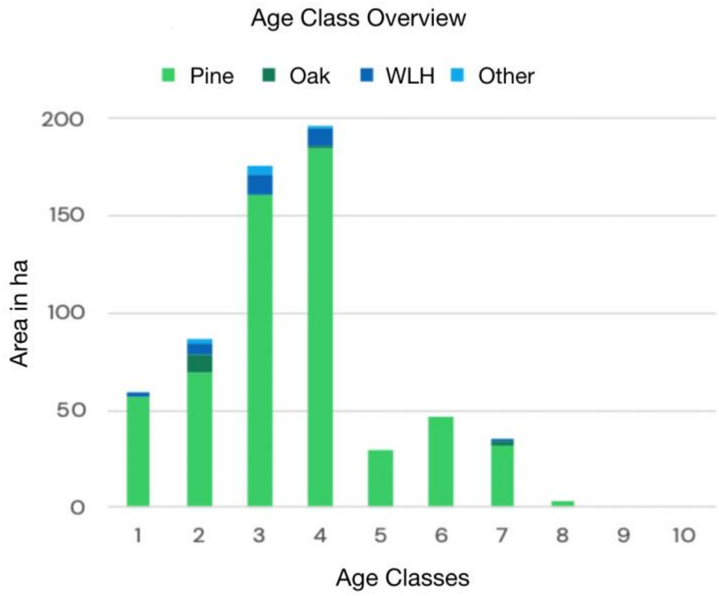

Figure 2: Age classes by tree species in the upper storey by area.

While the age classes 3 and 4 are disproportionately represented, the age classes 1 and 2 occupy below-average shares of the farm's acreage. Age class occupy below-average shares of the area in the farm. In addition, there are surpluses in the 6th, 7th and 8th age classes. However, the existing under storey on 186.01 ha is not included in this graph. If this were included in the first age class, a much more even distribution would result. Overall, the age class distribution on the Luckaitztal farm is unbalanced.

Stock, degree of stocking and increment

The real stock for the entire operation is 129,367 cubic meter of timber harvested (Efm). In addition, the real stock of the hold over is 1,784 cubic meters. The current annual increment for the entire operation is 4,694 cubic meters. Over all areas of the upper storey, a degree of stocking of 0.95 is reported. For the individual tree species groups, the actual stock, the current increment and the degree of stocking are as follows:

Tree species group	Pine	Spruce	Oak	SHL	WLH	Total
Real stock (Vfm)	124,959	312	958	433	2,705	129,367
Current increment (Efm/year)	4496	10	73	35	75	4.690
Degree of stocking	0.94	0.87	1.04	0.76	0.96	0,95

Table 5: Actual stock, current increment, and degree of stocking

3.5. Project-related technologies and services

GHG sequestration

The product of the GHG project is CO_2, biologically sequestered by the forest. This involves maintaining and increasing the GHG reservoir in the existing forest. An adaptation from age-class forest (GHG baseline) to plenter-type management (GHG project scenario) can yield up to 22% higher stemwood harvest and can result in substitution performance (Johann Heinrich von Thünen-Institut, 2010). A tree species change to higher-yielding species (e.g., Douglas fir) can also yield up to a 60% higher GHG sink than average (Johann Heinrich von Thünen-Institut, 2010). Further details on increment, end-use, and resulting stocks are described in Chapter 5.

Ecosystem Services

The GHG project creates climate-resilient, productive forests, thereby protecting habitats and essential ecosystem functions. These include (Fachagentur Nachwachsende Rohstoffe, 2021):

1. the contribution to climate protection by reducing GHG emissions in the atmosphere,
2. the long-term protection of the habitat for animals and plants, as well as safeguarding biodiversity through risk-reducing and biodiversity-promoting management measures,
3. promoting oxygen production, air filtration and cooling, water filtration and groundwater storage by preserving the forest and promoting forest growth,
4. maintaining the supply of raw materials for economic use and job security, especially in rural areas, as forests continue to be managed, and
5. the preservation and promotion of recreational, health and tourism value-added functions provided by forests.

3.6. GHG sink

The GHG project is expected to generate 29,061 t CO_2 (cf. Chapter 8) over the project life of 30 years and remove it from the atmosphere (gross GHG sink). This represents the difference between the GHG baseline and the GHG project. Here, the stock development on the GHG project area is based on the forest simulator TreeGrOSS (cf. Chapter 8.2).

The GHG sink is expected to increase, as shown in Table 6 and Figure 3. The GHG reservoir in the reference scenario refers to the total GHG reservoir capacity, consisting of the stock on the land, assuming no GHG project. This evolves from 212,119 t CO_2 in year 0 to 175,893 t CO_2 in year 30. The GHG reservoir in the project scenario, on the other hand, represents the GHG reservoir that is associated with the project activities defined forest adaptation measures described in Chapter 3.2 . This develops from 212,119 t CO_2 to 204,953 t CO_2. The gross GHG sink is calculated from the difference between GHG reservoir reference scenario and project scenario (cf. Chapter 8.4). The net GHG sink results from the gross GHG sink minus the risk buffer (cf. Chapter 8.5). For this GHG project, the risk buffer is 18.5% (cf. Chapter 3.7). Accordingly, the net GHG sink after 30 years is 23,684 t CO_2 . The issued certificate volume corresponds to the total net GHG sink after 30 years (cf. Chapter 8.6). One certificate has the value of one (1) ton of CO_2.

Years	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	212,119	212,119	0	0	0
5	180,493	166,305	-14,188	-2,625	-11,564
10	182,459	170,624	-11,835	-2,190	-9,646
15	182,432	182,971	539	100	439
20	185,602	194,956	9,354	1,730	7,623
25	179,638	199,592	19,955	3,692	16,263
30	175,893	204,953	29,061	5,376	23,684

Table 6: Projected GHG reservoir in project and reference scenario and GHG sink.

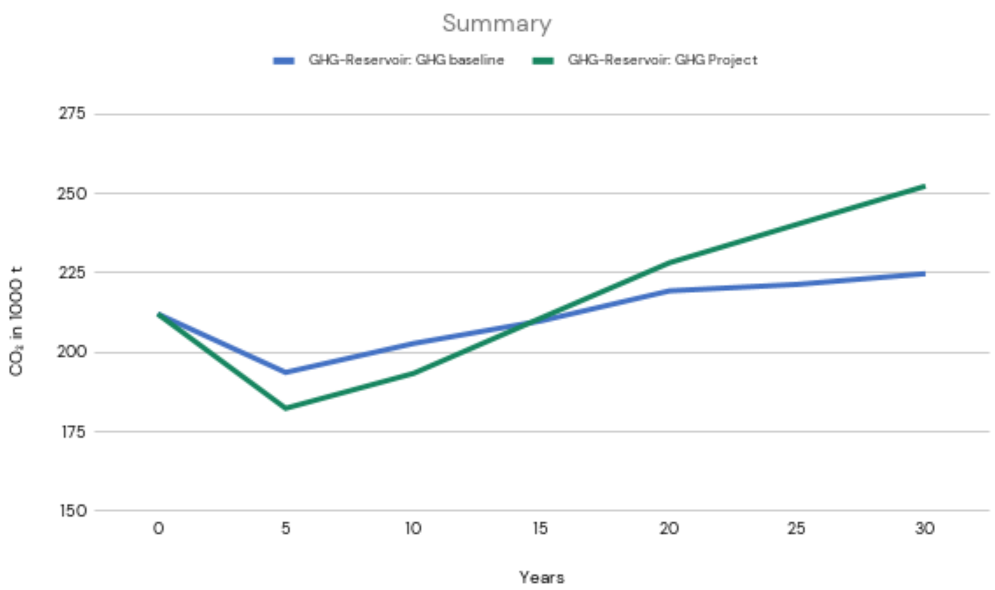

Figure 3: Projected GHG reservoir in the project and reference scenario

Further detailed information can be found in Annex 15. 6. Pina Technologies GmbH reserves the right to correct the original prediction if new knowledge is gained based on validation and/or science.

3.7. Risks

Based on the AFOLU (Agriculture, Forestry, and Other Land Use) Non-Permanence Risk Tool from the Verified Carbon Standard (Verified Carbon Standard, 2019), internal, external, and natural risks are considered for the GHG project. The total risk of **18.5%** is the sum of internal (**15%**), external (**0%**), and natural risks (**3.5%**). A relocation of activities or market transformation can be excluded by the GHG project.

Internal risk

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

The project implementers are qualified forest managers with many years of experience in the field of forest adaptation, who have contractually committed themselves to implementing the adaptation measures (cf. Chapter 3.2). This also includes the introduction of climate-adapted and native tree species on the GHG project area. According to the 2021 Corruption Perception Index, the risk of external actors entering the project area to illegally harvest timber is very low in Germany and is thus excluded (Transparency International e.V., 2022). Consequently, the project management risk is **0%**.

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 term. In addition, the percentage of farms that filed for bankruptcy was 0.06% in 2010, 0.05% in 2013 and 2016, and 0.04% in 2020 (Destatis, 2022a). 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).

The opportunity cost for the GHG project is minimal. The analysis is based on the alternative land use. In Germany, the change in land use is very unlikely, as this would require a separate permit under the Federal Forest Act §9 Preservation of the Forest (Bundeswaldgesetz, 1975). This ensures that the efficiency of the natural balance is not impaired. Furthermore, Germany has committed itself by signing the 'Glasgow Leaders' Declaration on Forests and Land Use' (UN Climate Change Conference UK, 2021) which aims to conserve and increase forests. According to the German Federal Environment Agency, the total forest area has also increased steadily since 1990 (Umweltbundesamt, 2021). Accordingly, the risk of opportunity cost is **0%.** (Verified Carbon Standard, 2019).

The risk to project longevity for the GHG project with a legally binding contract (see Annex 15.2) is **15%**, based on a project life of 30 years and is calculated as follows. (Verified Carbon Standard, 2019):

F1: $$Risk\ to\ project\ longevity\ [\%] = 30 - \frac{Project\ Life\ [Years]}{2}$$

External risk

External risk is composed of three risks: Land ownership and resource access risk, community involvement risk, and political risk.

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

Community involvement is not assessed for this GHG project because the local community does not rely on the GHG project area, e.g., for essential food, fuel, feed, medicine, 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 2016-2020, Germany receives a score of 1.47, as shown in Table 7. 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	2016	2017	2018	2019	2020	Average 2016 - 2020
Participation and accountability	1.36	1.43	1.43	1.36	1.38	1.39
Political stability and absence of violence	0.68	0.59	0.59	0.57	0.67	0.62
Government effectiveness	1.70	1.65	1.59	1.53	1.36	1.57
Quality of legislation	1.82	1.79	1.76	1.72	1.58	1.72
Rule of Law	1.62	1.61	1.63	1.62	1.59	1.61
Corruption control	1.83	1.84	1.94	1.90	1.86	1.87
Average of all indicators per year	1.50	1.49	1.49	1.45	1.41	1.47

Table 7: 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 measures (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%**.

Relocation risk

Changes in GHG emissions and withdrawn volumes due to GHG sources and sinks resulting from activity shifts (internal) or market adaptation (external) were considered. In this GHG project, the withdrawal volume in the GHG baseline is insignificantly different from the withdrawal volume in the GHG project scenario. As a result, the risk of internal and external displacement is negligible.

3.8. Actors

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

- **Project owner**: The project owner is the forest owner of the Luckaitztal forestry company and the owner of the GHG project area. The project owner is free to decide on the management within the legal framework.
- **Project implementer:** The project area is managed by the companies of the Boscor Gruppe and their foresters. This includes the implementation of the project measures. As professional forest managers, they have extensive experience in forest adaptation. They have a contractual relationship with the forest owner.
- **Project developer:** Pina Technologies GmbH has developed the 2021/2022 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.

Table 8 shows the contact information of the main actors:

Actors	Project owner	Project implementer	Project developer
Company	Forstbetrieb Luckaitztal	Boscor Gruppe GmbH	Pina Technologies GmbH
Name	[redacted]	Maximilian Freiherr von Rotenhan	Florian Fincke
Address	*	Reitzenstein 76 95188 Issigau	Vogelanger 7 82319 Starnberg
Phone number	*	+49 929394600	+49 15904163004

Table 8: Contact details main actors

*At the request of the project owner, the address and telephone number are not provided.

3.9. Environmental Impact Assessment

The GHG Project is not a project covered by the Law on Environmental Impact Assessment. Accordingly, an environmental impact assessment for the GHG Project is not required by applicable national legislation and regulations.

3.10. Consultation

The GHG project is being implemented on private land and the project activities do not affect any external stakeholders. Therefore, no other stakeholders were consulted for this GHG project.

3.11. Project flow

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

- **07/2021 - 12/2021:** Data were acquired, analyzed, and modeled using remote sensing and terrestrial inventory to quantify GHG emissions removed (cf. Chapter 8).
- **01/2022**: Project activities begin and continue over the life of the project as stated in the project contract.
- **05/2022**: The project description 'Forest Adaptation Project Luckaitztal' was completed and submitted to the validators and verifiers. After validation and verification, the GHG project will be registered and the GHG units will be sold (ex-ante).
- **01/2022 - 01/2052**: The period of the GHG project is 30 years. Accordingly, this is also the period of the GHG baseline as well as project. An extension is possible as long as a total period of 60 years is not exceeded. Verification of the GHG project is done after 3, 6, 10, 15, 20, 25 and 30 years after project start. After successful GHG project certification, the GHG units, as described in Chapter 8 described. The results are then published in a report.
- **01/2052**: Project activities are expected to be implemented over this date after the project ends.

The project duration is therefore from 01.01.2022 to 31.12.2051.

3.12. Eligibility

Pina Earth has formulated its own conditions of participation that apply to all GHG projects. These serve to provide additional assurance of the integrity of the GHG project. It has been ensured that this GHG project complies with them. The following generally applicable conditions of participation must be met:

Location

- The GHG project area is a forest within the meaning of the Federal Forest Act § 2 Forest (Bundeswaldgesetz, 1975).
- The GHG project area is located in Germany. Therefore, the following description can be executed based on national/site specific data, models and laws.
- The project area is not located in a national park, natural monument, nature reserve, biosphere reserve, land conservation area, nature park or Natura 2000 site. This requirement was determined for the project with the help of the Geoportal Brandenburg (Land Brandenburg, 2022). The GHG project area is therefore not subject to any existing legal encumbrance that restricts or prohibits commercial timber harvesting. This means that all planned measures 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 measures.
- 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 forestry technician or similar technician
    - 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.
    - Commercial register excerpt of the project implementer in the field of forestry consulting or similar consulting

Subsidies

The project owner has contractually assured that it will not receive 100% public funding for the planned project measures (see 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.

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 the project measures and the authorization for the project developer to market the GHG sink benefits in the voluntary market.
- The project owner is in a contractual relationship with the project implementer with respect to the project activities.

Ecological diversity

- When selecting the tree species and their mixing ratios in the target condition, the project owner shall ensure that they are site-appropriate and, if possible, native. This means that the choice of tree species and their mixing ratios corresponds to regional scientific recommendations of a recognized research institute, taking into account current climate and climate impact scenarios (Riek, Russ, & Grüll, 2020).
- The project owner shall ensure that, after 30 years, at least three (3) future, site-appropriate tree species are present on the GHG Project Area, with (each) at least 5% basal

area share of the GHG Project Area. The main tree species may take up a maximum of 70% of the base area of the total GHG project area.

- The project owner commits to increasing the diversity of tree species in the target condition through management. For this reason, the Shannon Index for tree species diversity must improve with each monitoring of the GHG project (compare Chapter 11.4).
- The project owner also guarantees that after 30 years there will be a regeneration layer on the entire GHG project area.

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. GHG reservoir/sinking

Table 9 explains all GHG reservoirs and sinks considered:

GHG reservoir	Consideration	Justification
Above ground living tree biomass	Yes	The aboveground living tree biomass may change substantially as a result of project activities. This GHG reservoir is controlled by the project proponent.
Subterranean living tree biomass	Yes	The below-ground living tree biomass may change significantly as a result of project activities. This GHG reservoir will be controlled by the project proponent.
Other living above/below ground biomass (shrubs).	No	Other biomass is not required due to insignificance (de minimis).
Deadwood (above/below ground)	No	The project measures do not include significant changes related to deadwood. Therefore, it has only a minor contribution to the difference in GHG emissions in the reference and GHG project scenarios. Total wood is therefore excluded due to insignificance (de minimis).
Scatter pad	No	Litter overburden is a smaller carbon pool (de minimis) and is generally considered only a transitional pool.

Soil Carbon	No	The project measures do not include significant changes in terms of soil carbon, at maximum they would be slightly positive. Therefore, it is only a minor contributor to the difference in GHG emissions in the Reference and GHG Project Scenarios. Soil carbon is therefore excluded due to insignificance (de minimis).
Wood product storage	No	GHG reservoir is not included for system delineation reasons.

Table 9: GHG reservoir and sinks

4.2. GHG sources

Table 10 explains all GHG sources considered:

GHG source	Consideration	Justification
Fertilizer use	No	Neither the GHG project scenario nor the reference scenario include the use of fertilizers, so these emission sources are excluded.
Biomass burning (slash and burn at project site).	No	Neither the GHG project scenario nor the reference scenario includes slash-and-burn, so these emission sources are excluded.
Fossil fuel combustion by vehicles /appliances	No	Emissions from harvesters, timber transport, and primary forest product manufacturing are not included (de minimis) because there is no significant difference between GHG baseline and project.

Table 10: GHG sources

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 forestry strategy' (Duda, 2006). The predominant stocking structure of the project area and still predominant operational form in Brandenburg originates from that of the age-class forest. Therefore, there are still large forest stands in which vertical and horizontal structural diversity is not satisfactorily present. This can be seen, among other things, in the data of the Federal Forest Inventory:

Only about 2% of the forest areas in Brandenburg are multi-layered or plentered (Johann Heinrich von Thünen-Institut, 2012). On a near natural rating from 1 (very natural) to 5 (very culture-dominated), 85% are rated 3, 4, or 5, and only 15% received a rating of 1 or 2 (Johann Heinrich von Thünen-Institut, 2012).

Clear-cutting (felling areas larger than 2 ha) is prohibited in Brandenburg (§10, LwaldG). Therefore, the GHG baseline does not simulate clear-cutting, but single tree removal. It follows that in the GHG baseline, the predominantly single-layer pure pine stand, as described in the baseline, corresponds to the average silviculture in the region and would be maintained without the GHG project. Each time the GHG project is monitored, the GHG baseline assumptions are reviewed. If there are significant changes to the reference scenario, this will be adjusted accordingly. Based on the current state of science, the GHG baseline, i.e., classical management, is defined in a standardized manner by the following parameters for the simulation of future development:

End use

In the GHG baseline, final harvest by target diameter is the default. Only pines with a breast height diameter greater than 40 cm are removed and tree selection starts at the largest dbh ('high thinning' cf. (Duda, 2006). In the GHG baseline, the removal volume is calculated with the prescribed yield according to Gerhardt's formula with a compensation period of 40 years (Bundesministerium für Ernährung und Landwirtschaft, 2017).

F2: Prescribed yield according to Gerhardt's formula:

$$H = \frac{lZ + dGz_u}{2} + \frac{V_w - V_n}{a}$$

The variables are defined as follows:

- H' = prescribed yield [Vfm]
- lZ = Current increment of the operating class [Vfm/year].
- dGz_u = Average total increment in age u of the operating class [Vfm/year].
- V_w = real stock of the real forest [Vfm].
- V_n = normal stock [Vfm].
- a = Compensation period for stock compensation (40 years in normal case) [years].

Thinning

High thinning is assumed in the GHG baseline. In order to represent an optimal and conservative thinning in the GHG baseline, the goal is to maintain the ideal basal area on the stand (according to thinning guide curve).

Natural rejuvenation, sowing, planting and hunting

In the GHG baseline, the tree species composition does not change over the project period. Although new trees are planted as soon as a stand falls below the typical canopy density level of 30% (Duda, 2006), the tree species composition and age classes do not change. The pure pine stand is thus preserved. Unlike the GHG project scenario, intensification of hunting does not occur. Given these facts, the number of regeneration plants is reduced to about 25% (cf. Chapter 8.2). This analysis is based on a study that examined the effects of game browsing on the condition of natural rejuvenation in Germany and the Czech Republic (Fuchs, Vacek, Vacek, & Gallo, 2021). The results show that without hunting, on average 78% of natural rejuvenation was damaged by browsing across tree species. In particular, the height of natural rejuvenation was reduced by 40% due to browsing on the terminal shoot. Browsing also affects the quality and abundance of natural rejuvenation. Accordingly, 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

From year 1 to 10 of the GHG project scenario, the end-use volume is increased by 20% (120% of Gerhardt's prescribed yield). From year 11 to 30, the end-use volume is again decreased by 20% (80% of Gerhardt's prescribed yield). This creates more space for natural rejuvenation and planting in the forest during the first years and promotes the adaptation to a more natural permanent forest.

Thinning

In the GHG project scenario, target trees are first selected in a high thinning and their distressers are removed. The selection of the thinners starts with the highest tree ("high thinning"). In this way, a multi-layered stand structure is aimed for (Duda, 2006). Overall, the volume of thinning is increased by 20% in years 1 to 10 compared to the reference scenario and decreased by 10% in years 11 to 30 compared to the reference scenario. As in the case of end-use, this creates more space for natural rejuvenation and planting in the forest in the early years and promotes adaptation to a more natural permanent forest.

Natural rejuvenation, sowing, planting, and hunting

In the GHG project scenario, the targeted tree species composition is based on the recommendations of the German state of Brandenburg (Riek, Russ, & Grüll, 2020). The recommendations specify different tree species and percent ranges of tree species mix proportions. In choosing the tree species composition, care was taken to keep the pine percentages as low as possible to promote a stronger mixture. High-growth conifers such as Douglas-fir and fir or more climate-stable deciduous trees are mixed in with the pine. Accordingly, the diversity as well as the climate resilience of the stands is increased. The goal of a permanent forest is permanent crown closure. The critical canopy density level, below which planting in a stand occurs, is therefore 80%. Additionally, because the GHG project is a new revenue source, planting can occur at twice the density in the project scenario compared to the reference scenario. In addition, 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 browsing of cloven-hoofed game 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 75% instead of 25% of all regeneration plants survive (Hothorn & Müller, 2010).

In the first few years, use outweighs increment. However, with regard to the entire project duration, increment is significantly higher than utilization, since the development of the under storey is promoted by initially thinning more, especially in older stands, and subsequently planting more. With respect to the entire project duration, the total utilization volume from the final utilization and thinning remains constant compared to the reference scenario with a maximum deviation tolerance of 5%. Thus, the GHG sink is not achieved through reduced management, but through the establishment of a under storey and resulting higher growth.

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 GHG SSR mentioned 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 GHG SSR mentioned 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. Digital Twin Structure

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 circular sample data from the forest inventory's measurement list, which was recorded in a grid of 200m x 200m. The sampling error of the forest inventory for this GHG project is 7.89% (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. In Figure 4, the trees with measured height and dbh values are shown as green points. These points form the basis for the created height curve. In addition, the measurement list describes for how many hectares the sample is representative. This is calculated by dividing the area of the stand by the number of samples in that stand. There is no evaluation on the part of the forest manager on the accuracy of the sample inventory at stand level, but only at farm level by the standard error mentioned above.

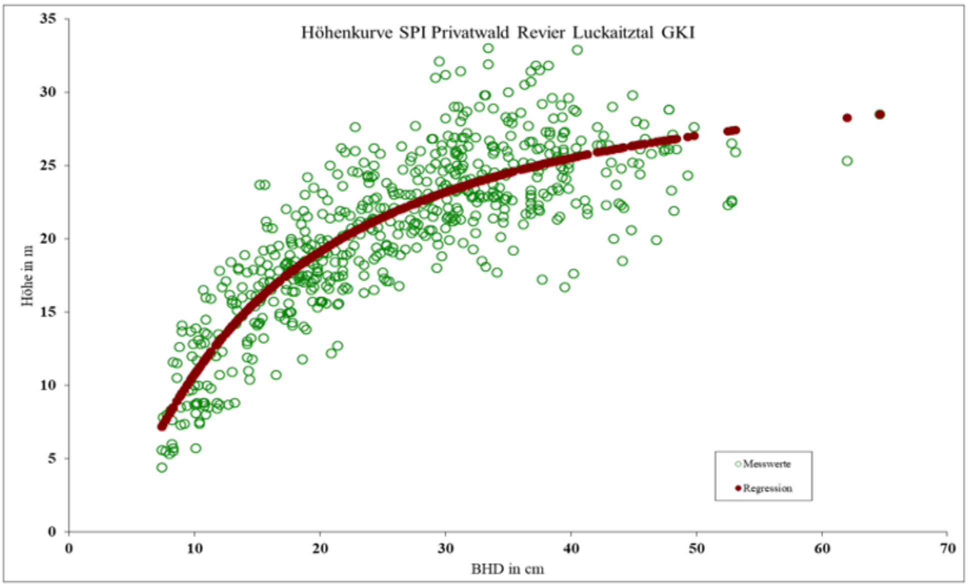

Figure 4: Height curve from the present inventory by TSS forest planning.

In the digital stand generation, a representative stand is generated per sample point, which is later simulated in the forest simulation as an independent unit, independent of the other stands. Different management strategies can thus be defined per stand. Thus, for example, a young spruce stand is treated differently than an old beech stand. The digital stand generation performs the following steps:

1. All trees are read in from the measurement list.
2. 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.

3. Each tree is written into the database with the following characteristics: Tree species, age, height and HDB. The position of the trees is selected pseudo-randomly to distribute the trees evenly, but still with varying distances. Other values, such as crown height, are automatically filled in via completion routines for missing values in TreeGrOSS.

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 height 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 farm 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 the further quantification steps. Therefore, the applicability of TreeGrOSS without a new parameterization is given for the present 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 by means of an example.

Mortality

TreeGrOSS also 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, et al. (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. To determine the climate-induced mortality probability, survival time models according to Brandl (Brandl, Paul, Knoke, & Falk, 2020) With data from regional climate models of the Potsdam Institute for Climate Impact Research PIK e.V. (Potsdam-Institut für Klimafolgenforschung (PIK) e. V., 2022) Used.

The input parameters of the survival time models are as follows:

- Tree parameters: Tree species, age, and proportion 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 time models results in the 5-year climatic survival probability for each tree at each time point in the simulation $\hat{S}_{5,Klima}$which is stored in the model.

The model of Brandl et al. does not include site-specific parameters apart from temperature and precipitation. However, drought stress, which depends on soil water storage, is of particular importance for the climate-induced mortality of local tree species. Therefore, the results of the models are additionally provided with a factor based on the local site water balance and a species-dependent drought stress risk.

According to Spellmann et al. (Spellmann, Sutmöller, Schulz, & Nagel, 2020) The site water balance (SWB) results from the sum of the climatic water balance (KWB) and the usable field capacity (nFk).

F3: Site water balance

$$SWB = KWB + nFk$$

The variables are defined as follows:

- SWB is the site water balance
- KWB is the climatic water balance
- nFk is the usable field capacity

The climatic water balance, like the climate parameters, can be taken for each year of the simulation from the climate models of the Potsdam Institute for Climate Impact Research PIK e.V..

For the determination of the usable field capacity of each stock, the soil type is based on the data of the soil survey maps 1:200,000 of the Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, 2022) Is used.

Following Spellmann et al, a low, medium, or high drought stress risk is then determined for each tree species depending on the available site water balance. On this basis, the site factor F_s is determined, which is stored in the model. A low drought stress risk is assumed to have a site factor of 0%, a medium 30%, and a high 50%.

On the basis of $\hat{S}_{5,Climate}$ and F_s the final 5-year survival probability is then calculated for each tree:

F4: 5-year survival probability

$$\widehat{S_5} = \hat{S}_{5,Climate} \times (1 + F_s)$$

The variables are defined as follows:

- $\widehat{S_5}$ 5-year survival probability
- $\hat{S}_{5,Climate}$ 5-year climatic survival probability
- F_s Location factor

For each simulation step it is now compared whether the value $\hat{S}_5$ 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 is $\hat{S}_5$, e.g. 0.5 (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 is $\hat{S}_5$ 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-related 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, crown attachment, and crown width for an assumed parabolid, 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 canopy 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 canopy 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). The formulas to calculate the site index are given in Annex 15.5 listed.

Management

The Silviculture software package associated with TreeGrOSS makes it possible to simulate diverse management measures, such as thinning, end-use, or planting (Hansen & Nagel, Das Paket Silviculture für die automatisierte Simulation waldbaulicher Szenarien, 2016) Since there is no setting for promoting natural rejuvenation, additional rejuvenated trees are approximated using the planting mechanism. That is, the total number of planted and naturally regenerated trees depends on the canopy density level in the GHG baseline (cf. Chapter 5.1) and GHG project scenario (cf. Chapter 5.2). As soon as the crown density level is fallen below, new trees are planted or naturally regenerated on the site. The tree species composition was determined in Chapter 3.2 explained. If the tree species of the new tree is already present on the GHG project area, then it is declared as naturally regenerated. If the tree species of the new tree is not yet present on the GHG project area, then it will be planted. For example, if a pine tree is planted in a pine stand through the planting mechanism, then it is declared as a naturally regenerated tree. However, if a Douglas fir is planted in a pine stand, it will still be labeled as planted.

Since TreeGrOSS distinguishes naturally regenerated and planted trees only by the assigned name, but not in growth behavior, this does not create a difference in growth. The influence of increased hunting is critical to the higher number of regeneration plants in the GHG project scenario. However, TreeGrOSS does not provide settings and inherent mechanisms for this. The default TreeGrOSS setting unrealistically plants more regeneration plants for this reason. This finding was confirmed by Jan Hansen of the Northwest German Forest Research Institute (responsible for the development of TreeGrOSS) and the project implementers. Therefore, an expert factor was introduced to realistically simulate the effect that more regeneration plants survive during intensive hunting. Accordingly, this factor reduces the number of regeneration plants to 0-100%. Due to intensive hunting in the GHG project scenario, it is assumed that 75% of regeneration plants survive (Hothorn & Müller, 2010), while 25% is assumed in the GHG baseline with occasional hunting (without a hunting plan) (Fuchs, Vacek, Vacek, & Gallo, 2021). Thus, 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 assumptions for end-use, thinning, planting, regeneration, and seeding differ depending on the GHG baseline and GHG project scenario (cf. Chapter 5).

8.3. Quantification GHG reservoir

Total carbon of aboveground and belowground 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.

F6: 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 F7).
- 0.5 = Biomass to carbon ratio (Diestel & Weimar, 2014)
- 3.667 = Carbon to CO_2 by molar mass ratio

F7: live tree biomass for the year. t [kg]

$$LB_t = \sum_i^{n\ trees} B_{above,i} + \sum_i^{n\ trees} B_{below,i}$$

The variables are defined as follows:

- $B_{above,i}$ = Above-ground biomass of tree i [kg] (cf. Formula F9).
- $B_{below,i}$ = Belowground biomass of tree i [kg] (cf. Formula F8).

F8: below ground biomass of tree i [kg]

$$B_{below,i} = B_{over,i} * RTSR$$

The variables are defined as follows:

- $B_{above,i}$ = Aboveground biomass of tree i [kg] (cf. Formula F9)
- $RTSR$ = root-to-shoot ratio (Wördehoff, Spellmann, Evers, Aydin, & Nagel, 2012; Intergovernmental Panel on Climate Change, 2003)

F9: above ground biomass of tree i [kg]

$$B_{over,i}$$

The calculation of aboveground 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) available.

8.4. Gross GHG emission reduction

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

F10: 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 CO_2 in the GHG project scenario, estimated for yr. t [CO_2] (see Formula F6).
- $\Delta CO2_{reference,forest,t}$ = Change in forest CO_2 in GHG baseline, estimated for yr. t [CO_2] (see Formula F6).

8.5. Net GHG emission reduction

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

F11: 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 F10)
- R_t = Risk buffer for the year t [CO_2] (cf. Formula F12)

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.

F12: risk buffer for the year t [%]

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

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 F10)
- R_{nat} = Natural risks for the year t [%]
- R_{fin} = Financial risks for the year t [%]
- R_{mng} = Risks project management for the year t [%]
- R_{lan} = Natural project longevity for the year t [%]
- R_{pol} = Political risks for the year t [%]

8.6. Number of certificates

The number of allowances is calculated from the total quantified net CO_2 reduction and removal over the GHG project life from year 0 to year 30. The issuance of the *ex-ante* allowances follows the validation.

F13: Number of allowances less risk buffer worth one metric ton of CO_2 for year t

$$Z_{net,t} = \sum_{t=0}^{t=30} CO_{2\ net,t}$$

The variables are defined as follows:

- $CO_{2\ net,t}$ = Total net quantified CO_2 reduction and removal for the year. t[CO_2] (cf. Formula F11)

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 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) adapted. Accordingly, the GHG project was based 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 was also addressed under the latter Chapter.

9.1. Legal additionality

The GHG project is basically voluntary. This means that at the beginning of the project, the GHG project and the planned measures are not required by law. These include, but are not limited to, the Federal Forest and Nature Conservation Act (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 it is 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 level of performance (in terms of GHG reservoir) of general practice 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 TGH reference scenario. For successful certification, the forest owner must demonstrate target action planning for the GHG project. The simulation of the GHG project scenario insists on these mandatory committed forest adaptation measures. The results of the quantification in Chapter 3.5 show that a higher emission reduction performance is achieved in this way. This ensures the performance-based additionality of the GHG project.

9.3. Financial Feasibility and additionality

In both scenarios, extraction is assumed to occur at the fiscal prescribed yield over the life of the project (cf. Chapter 5.1 and Chapter 5.2). This approach corresponds to the standard in Germany and can therefore be assessed as financially feasible. According to the accounting results of the test farm network forest of the Federal Ministry of Food and Agriculture, harvesting has even been mostly above the prescribed yield in recent years (Bundesministerium für Ernährung und Landwirtschaft, 2022), showing that the assumptions are conservative.

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 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, and intensified hunting (to promote natural rejuvenation).

At the same time, a similar amount of stock is removed and thus timber is sold in both scenarios. In the GHG project scenario, however, the trees are removed earlier (reduced target diameter and/or initially increased removal volume) resulting in less valuable assortments going into the sale.

Since both the cost of the GHG project is higher and the revenue is lower than that of the GHG baseline, financial additionality is present.

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 reservoirs 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 sampling error according to the forest inventory is 7.83% (cf. Annex 15), i.e. significantly 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 (13m radius) each per 2 ha area. 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 reservoir on the GHG Project Area. In particular, the purpose of the monitoring is to examine the following:

- Successful execution of the tasks described in Chapter 3.2 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 measures

The data described in Chapter 3.2 defined 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 measures and forest condition will be reviewed and documented over the GHG project period. All measures, such as promoting natural rejuvenation by thinning the upper storey or introducing new climate-resilient tree species through planting or seeding, are expressed in both the under storey and upper storey. Therefore, monitoring draws on a range of different data. These include inventory data, data from photo documentation and evaluation, and remote sensing data.

Firstly, the relevant data from the forest inventory, which is published every 10 years, is checked. It is controlled how the size of the regeneration areas develops over the course of the project.

In addition, the results of the project measures, 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 cue point per stand. GPS inaccuracy may be +/- 15 meters. Seeding and planting will be documented at the project action 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 proportions, height stage proportions, frequency of browsing and form damage. Optional information on seeding and planting includes number of new trees and tree species proportions. This is followed by evaluation by Pina Earth. Results are compared to the most recent regeneration status and assessed. 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 storey is monitored by remote sensing (cf. Chapter 11.3). A stronger thinning of the upper layers, especially in the overstocked stands, should be clearly visible.

11.3. GHG reservoir monitoring

11.3.1. Evaluation of remote sensing data

The quantification of the GHG reservoir is calculated for each monitoring according to the steps in Chapter 8. The only difference is that Pina Technologies GmbH plans to use the digital twin (cf. Chapter 8.1) to be based 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 storey of the forest is developing. Likewise, disturbances caused by natural causes such as storms or by a deliberate disregard of the management plan by the project implementer, such as excessive use or clear-cutting, can be identified. 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 at random 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 6 shows a bird's eye view of a section of the GHG project area. The brighter a pixel is, the taller the tree is.

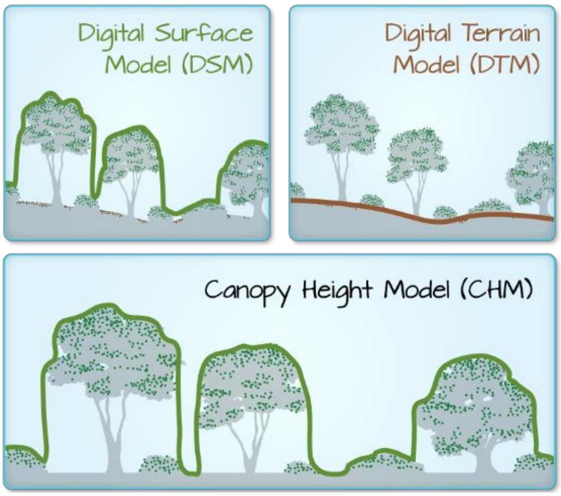

Figure 5: Canopy Height Model

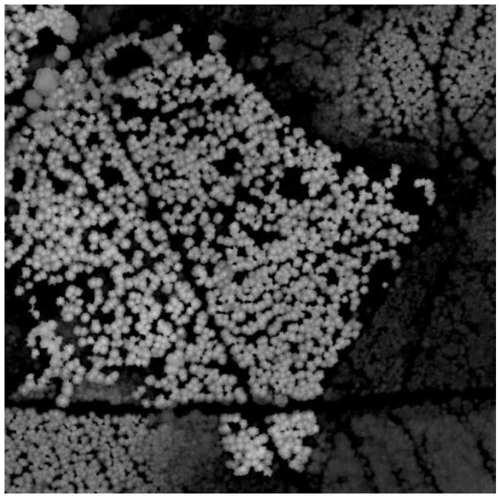

Figure 6: Section CHM from GHG project

Step 2 – Division into homogeneous departments

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 tree species mix. First, the GHG project area is divided into the divisions predefined by the forest owner in the forestry planning (cf. red boundaries in Figure 7, 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 7 right). In the following, these new subdivisions are referred to as stands.

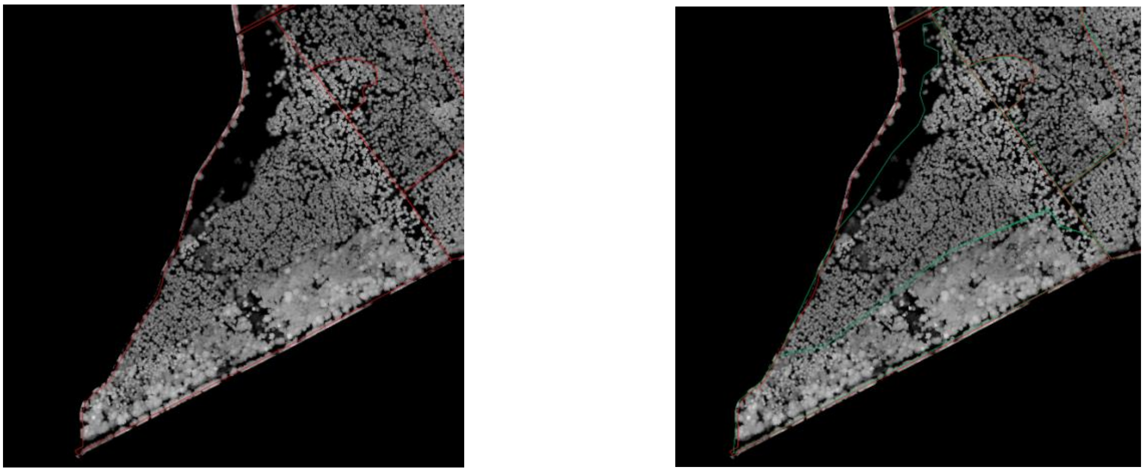

Figure 7: Section Departments (left) and Sub-Departments (right)

Both the CHM (cf. Figure 8 left) and the RGBI data (cf. Figure 8 right) are repartitioned based on these boundaries.

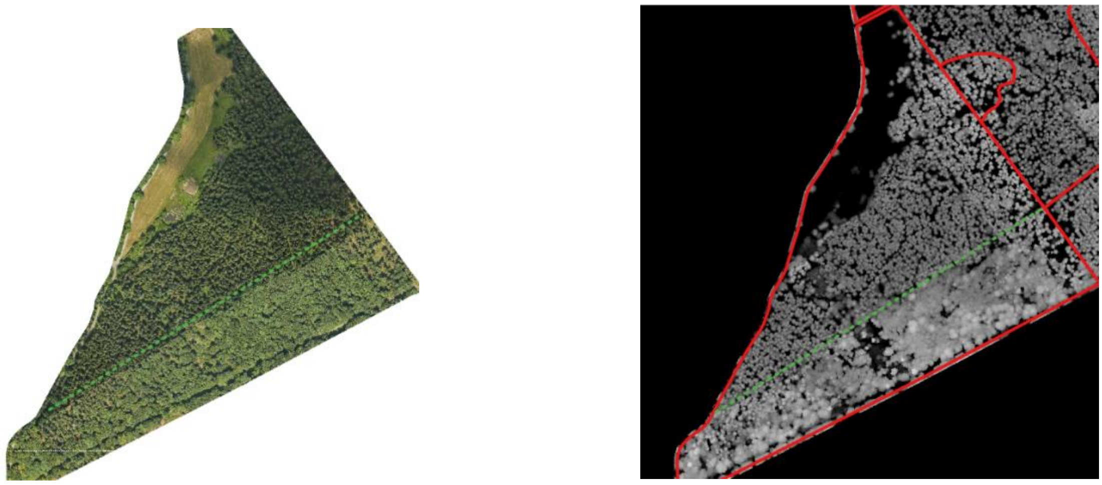

Figure 8: Section of subdivisions RGBI (left) and CHM (right)

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 7cm and thus have no significant biomass. To generate the position of the tree tops (cf. Figure 9 left), the highest pixels in this stand are identified and from there 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 9 right). This information is needed for the classification of the tree species in the following Chapters.

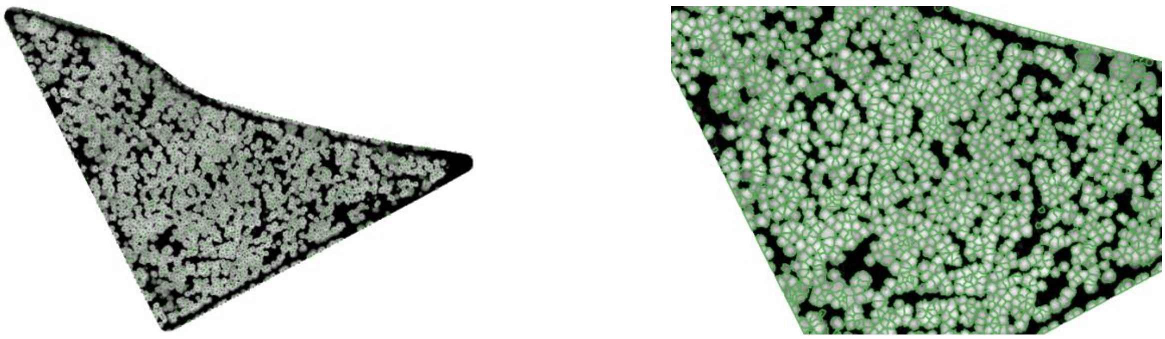

Figure 9: Section of tree tops CHM (left) and tree tops (right).

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). The Figure 10 shows that the classification algorithm detected two clusters, 70% conifers and 30% deciduous trees, for this section of the GHG project area.

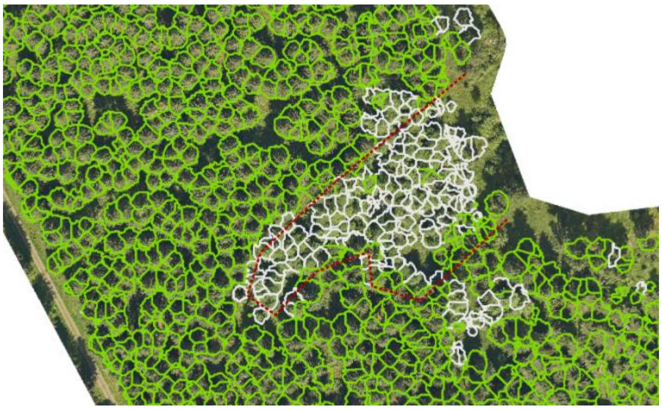

Figure 10: Section classification coniferous and deciduous tree species

Step 5 - Assignment of the trees

In this step, the trees previously detected by remote sensing (cf. red dots Figure 11) are compared with the random terrestrial inventory data (cf. blue dots Figure 11) 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.

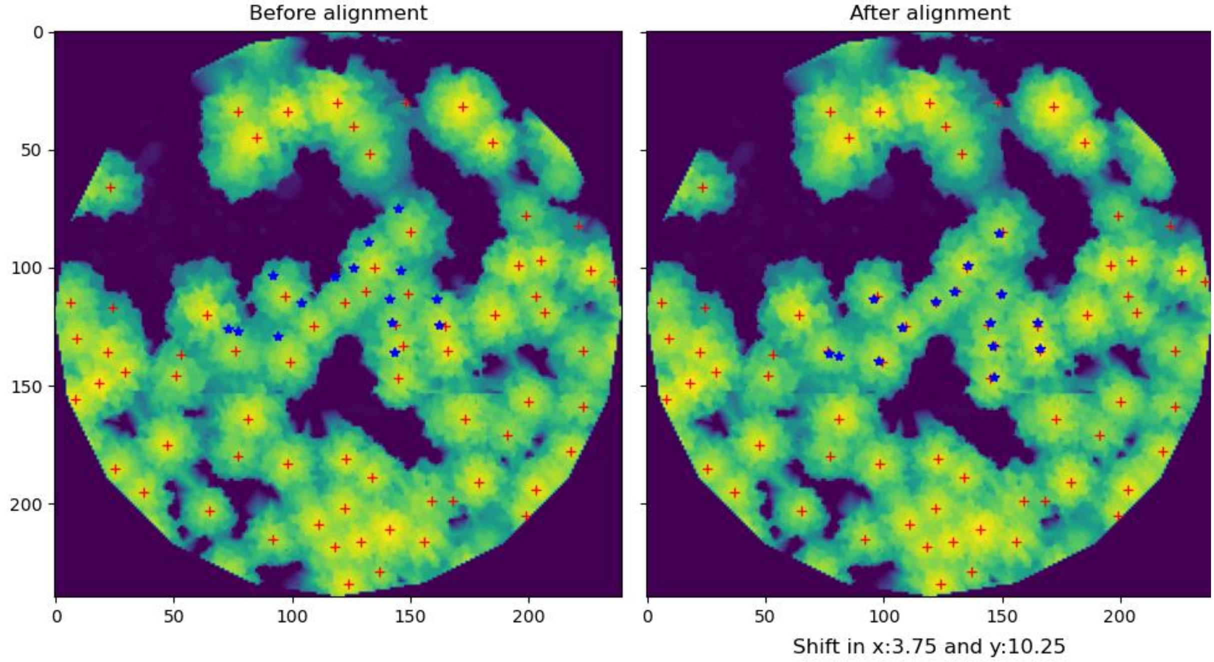

Figure 11: Detail allocation of remote sensing and inventory data

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) 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 is the trunk count of the algorithm 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.

F14: calculation of number of trunks in plot p [number of trees per hectare].

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

The variables are defined as follows:

- n_p = number of trees in plot p

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).
- Tree species composition 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 root number of the remote sensing data (cf. step 6).

Step 8 – Digital stock 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 tree species composition 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. calculated the number of trees in the entire stand based on the tree density of the corrected inventory data.
    b. calculated the distribution of tree heights and HDD 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. For small groups with less than 5 trees, a standard deviation of 25% is assumed for height and HDB 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 HDB. 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 will be compared. 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 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 therefore be reviewed at the intervals specified in Chapter 11.1. 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 forestry data or are based on the remote sensing data and are the following:

Parameter	Number of trees per stand
Data unit	Quantity
Description	Number of trees per stand
Source	Sampling inventory data from the forestry survey
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 survey (cf. Chapter 10)
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 inventory data from the forestry survey
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 survey (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 inventory data from the forestry survey
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 survey (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 inventory data from the forestry survey
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 forest survey (cf. Chapter 10)
Intended use of the data	Needed to calculate GHG reservoir in the reference and project scenarios.

Parameter	Trees height
Data unit	Centimeter
Description	Height, measured or assigned for each tree in the project area.
Source	Sampling inventory data from the forestry survey

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 comes from the forestry survey and has a sampling error of 7.89% (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 GHG reservoir do not originate from data collected at the project site. The fixed parameters fall 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	Root to shoot ratio
Data unit	%
Description	The root-shoot ratio results from the weight or volume of above- and below-ground biomass. This ratio describes the vigor of the complete plant and its ability to root soils accordingly.
Source	(Wördehoff, Spellmann, Evers, Aydin, & Nagel, 2012; Intergovernmental Panel on Climate Change, 2003).
Value used	Tree dependent
Justification for the selection of data or description of the measurement methods and procedures used.	Generally accepted method for calculating the belowground biomass of trees
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 derb 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 aboveground 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 measures 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 in the stand.

$$H' = -\sum_{i=1}^{s} p_i * \ln p_i \text{ with } p_i = \frac{n_i}{N}$$

The variables are defined as follows:

- H' = 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. The minimum value is 0, which means that all trees in the stand are assigned to one tree species. The maximum value is 1, which means that each tree species consists of the same number of trees.

$$E = \frac{H'}{H_{max}} \quad \text{mit} \quad H_{max} = \ln s$$

The variables are defined as follows:

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

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

Simulation step	Shannon Index	Evenness
Year 0	0.146002	0.183881
Year 5	0.873751	0.449760
Year 10	0.855922	0.425219
Year 15	0.863913	0.423813
Year 20	0.859733	0.414305
Year 25	0.834225	0.400552
Year 30	0.831920	0.399173

Table 11: Shannon index and evenness of tree species.

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

11.5. Roles

The monitoring of the forest adaptation measures 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. In 2021, Aeromap GmbH was contracted to collect remote sensing data. The 2021 inventory was conducted by the setter TSS-FORSTPLANUNG Thode, Setzer, Spinner & Partner.

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 reservoir 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 Chapter 6.11

Regarding documentation requirements according to Chapter 6.11 of *DIN EN ISO 14064-2:2019 see <u>Chapter 11.6.</u>*

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 after half 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 allowances distributed
- In the event of an initial overestimation of the GHG emission reduction, allowances are withdrawn 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 requirement of ISO 14064-2, Chapter 5.13 and provided to the intended users.

15. Annex

#	Name	Format	Comments
15.1	Forest Management	pdf	
15.2	GHG project contract	pdf	
15.3	Natural risks	xlsx	
15.4	Formulas TreeGrOSS	xlsx	
15.5	Example TreeGrOSS	xlsx	
15.6	Results GHG sink	xlsx	
15.7	Forest land map with parcels	pdf	
15.8	Forest base map with sampling point grid	pdf	
15.9	Monitoring concept app	pdf	

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