CO_2 Quantification Method - EcoTree

EcoTree is a company specialising in the ecological and economic development of forests and their renewal. EcoTree offers individuals and companies the opportunity to invest in the creation and maintenance of forests by becoming tree owners on properties owned by EcoTree or third parties. By becoming owners, our customers support the ecological well-being of the forests and receive the income. All forest management is carried out by EcoTree teams using a close-to-nature silvicultural approach. In this way, EcoTree seeks to make the most of all the multifunctional aspects of the forest, including carbon capture. In 2019, EcoTree therefore developed the first version of a tool which, based on forest yield tables, makes it possible to quantify the carbon in our forests. This method is constantly being improved, for example to take account of the wood industry's products and their substitution effects, ensure the permanence clause, etc. Bureau Veritas has verified the applicability of this method to the afforestation projects carried out by EcoTree.

Keywords: carbon sequestration, carbon stock in woodproducts, substitution, SMCC (continuous cover mixed species forest management), SMLT/LTA (Long term average)

Sommaire

1 Introduction

As a reminder, this method is based on a model, which takes as input values a yield table (i.e. a species associated with a fertility class), an area and a reference scenario; and returns the values corresponding to the 3S of carbon (sequestration, stock and substitution, see chapter2.).
In this document will be detailed each of the stages of the calculation process (chapter|3), as well as the method used to create the yield tables (chapter 6). The presentation of the four pillars of carbon credits (or more depending on the verification methods used) will be the subject of a justification on the merits of this method (chapter4).

Given the importance of carbon in the fight against global warming, EcoTree has worked to develop a tool that quantifies the overall carbon storage expected from each tree stand, based on the silvicultural yield tables chosen. EcoTree's customers can thus see the benefits of good forest management in terms of carbon storage.
Although this quantification tool is based on the quantification equations of the Label Bas Carbone [Label Bas Carbone, 2020a, Label Bas Carbone, 2020b] Version 2 of 27/07/2020, it differs in that EcoTree does not limit its calculations to 30 years, but quantifies the carbon stored throughout the life of the trees and the concept of LTA "infinity" is introduced (chapter 5).
A method for quantifying the additional carbon for a change in silviculture towards continuous-cover mixed species silviculture is proposed (chapter 8).

This method does not take into account aspects relating to the preservation of biodiversity, although it does propose justifications and elements for calculating carbon in forestry projects. However, on the one hand, the choice of mixed forestry with continuous cover is a strong position that goes in this direction. On the other hand, the valuation of biodiversity in the context of the market for contributions to the fight against global warming could be the subject of a publication or a specific method. The same applies to the valuation of ecosystem services other than wood products and carbon storage.

All technical terms used in this document are defined in a glossary, chapter 2.

2 Glossary

The following terms are taken from the "glossaire forestier canadien" [Canada Forest Service, 2023].

Cutting cycle: time between two successive cuts of the same type in the same plot. Ex: 12-year cycle for thinning deciduous trees.
Rotation: time it takes for a stand to renew itself between two clear cuts or successive regenerations.
Dominant height: average total height of the hundred largest trees per hectare in a stand.
Basal area: A measurement used to help estimate forest stocking: the sum of the stems' cross-sectional areas 1.3m above the ground. It is therefore expressed in m2/ha.
Timber volume: a tree's wood volume for a cutting diameter, down to 7 cm.
Litter: The uppermost layer of the soil, composed of freshly fallen or slightly decomposed organic matter and debris. It hosts an ecosystem of decomposing organisms which gradually transforms it into humus (Source: futura-sciences).
Humus: upper layer of the soil created and maintained by the decomposition of organic matter, mainly by the combined action of animals, bacteria and fungi in the soil; it is dark in color because it contains a lot of carbon (Source: actu-environnement).
Productivity: increase in the volume of woody material (in m3/ha/year).

The following terms are related to carbon calculations.
The "3 S":

- Sequestration (in biomass): trapping CO2 in biomass through photosynthesis.
- Storage (in products): storage of CO2 in wood industry products (furniture, crates, beams, shavings, etc.).
- Substitution: replacing fossil energy sources (coal, oil, etc.) or the use of energy-intensive and/or polluting materials (aluminum, concrete) with wood. The quantities of carbon avoided by using this renewable material rather than a non-renewable one are called substituted. The substitution coefficient depends on the type of wood product: BO, BI, BP or BE.

Biomass: mass or total amount of organic matter from organisms living in a particular area at a given time.

- Biomass of a tree: aboveground biomass + root biomass.
- Above ground biomass: includes the trunk and crown.
- Root biomass: includes the root system in the ground.

Infradensity: ratio between the mass of dry wood and the volume of green wood = dry mass contained in the wet volume.

tDS: tonne of dry mass, this is the metric used to calculate the volume before going into carbon assessment (carbon rate = 0.475 tC/tDS) then carbon dioxide equivalent.

Carbon vs Carbon Dioxide (C/CO2): Some documents use carbon rather than carbon dioxide as a value. The fraction of carbon in carbon dioxide is the ratio of their weights. The atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44, since it includes two oxygen atoms that each weigh 16. So, to switch from one to the other, we must use the formula: One tonne of carbon is equivalent to 44/12 (tCO2/tC) = 3.67 tonnes of carbon dioxide. Thus, 11 tonnes of carbon dioxide equals 3 tonnes of carbon.

SMLT/LTA: "Stock Moyen à Long Terme", i.e. Long-Term average (LTA) from the Verra method) is a value in relation to the permanence clause of carbon credits. This notion is explained in chapter5).

Anticipated emission reductions (AER): AER takes standing trees' carbon storage into account (forest AER), and carbon storage in wood products (AER products). They are calculated by a difference between the project scenario and the reference scenario (i.e. if the project was not implemented).

Indirect emission reductions (IER): the substitution that the use of wood products from the AER products is calculated. For this, a substitution coefficient is applied according to the type of wood.

Bilan EcoTree: is the difference between the carbon captured by the project (sequestration and wood product stock) and the carbon captured by the reference scenario at t = 100 years. This value is purely indicative.

Note: EcoTree uses some of these values to show the results, they are detailed in chapter7.
Pourcentages BO-BI-BP-BE: BO = T; BI = YL; BP = PW and BE) FW. T-YL-PW-FW percentages: T = timber (frames, beams, joinery, etc.); YL = yard lumber (pallets, panels, etc.); PW = pulpwood; FW = fuel wood (forest chips, logs, etc.). Depending on the diameter and the quality of the cut trunks, they are distributed among these different categories. Prices and lifetimes also depend on it: $FW < PW < YL < T$.

Half-life: time after which half of the carbon (or CO2 equivalent) stored in the wood is returned to the atmosphere due to the degradation of the material. It depends on the type of wood product: T, YL, PW or FW. This is precised in chapter11.

3 Chronology of a carbon calculation

Entry data/parameters are:

- species and fertility class
- management regime: even-aged or uneven-aged (SMCC)
- surface of the evaluated tree stand
- reference scenario for the tree stand

The species and fertility class are represented by the yield table, which details the evolution of the wood volume over time. The forest site (i.e. the climate, soil and geology) dictates the fertility class and is the subject of a study carried out internally or by an external expert. These studies also recommend which species are likely to survive in the first few years after planting, but also over the long term, according to the IPCC's warming scenarios. These justifications are included on the certificate provided when the calculations are verified. Fertility is categorised into three classes, f1: growing fast, f3: not growing very much.

During a field study, soil data is collected (water retention coefficient, pH, soil type) and the surrounding vegetation is assessed. Similarly, meteorological data is researched on the appropriate databases (temperatures, average and extreme rainfall), as well as the geology of the site. These data are used to assess the fertility class of the species chosen and are provided to the expert who validates the itineraries for each stand.

Here is the calculation process:

(i) calculation of forest biomass carbon; from the production table selected by species and fertility class, a linear interpolation is carried out between each thinning, except between planting and the first thinning where a 2nd order polynomial interpolation is carried out (in the case of a calculation for LBC metrics, an exponential interpolation is used). This only influences the 100-year (or 30-year) REA calculation and not the LTA "infini" calculation,

(ii) calculation of carbon from other compartments (litter, soil, dead wood),

(iii) calculation of carbon from the reference scenario,

(iv) calculation of the AER forest metrics at 30 or 100 years (depending on the metric sought) or using the LTA "infinity" (for uneven-aged forestry); these metrics are explained in chapter7,

(v) calculation of carbon stock in wood products,

(vi) calculation of the AER metrics produced at 30 years and 100 years or using the LTA "infinity",

(vii) calculation of substitution effects and IER,

(viii) calculation of the total AER as well as the value specific to EcoTree and the present method.

4 The four pilars (or criteria) of carbon credits

This section details the four main criteria for the validity of carbon credits and why the EcoTree method meets these criteria. We consider these criteria to be safeguards that guarantee the quality and robustness of this method.

However, this method only specifies how the various metrics of the 3S are calculated; it does not cover the legal aspects or describe which projects are accepted or not. It comes after these considerations in the process. As specified below, where necessary, the other criteria that will determine whether or not a project is accepted (legal, economic) are assessed during the project design phase, i.e. for example the choice of land, the search for a baseline scenario, the validation of mandatory criteria, etc. before the calculation phase.

4.0.1 Unicity

A carbon credit can only be used once, by a single entity, in order to avoid issues of double accounting, i.e. if two entities claimed the same project to have captured 100 tonnes of CO2eq. it would be assumed that 2 x 100 tCO2eq. = 200 tCO2eq. had been captured, when in reality the total captured represented only 100 tCO2eq.

To avoid this kind of situation, the major players in the carbon market have set up registers in which they record the credits associated with each project individually, allocating a unique reference to each one.

This constraint is not taken into account by this method. On the other hand, it is clear that procedures have been put in place to comply with it, but this is not the aim of this method.

4.0.2 Additionnality

Everything is calculated against a baseline scenario, which represents what would have happened if the project had not been carried out. The fact that the emission reductions would not have occurred in this reference scenario must be proven.

Physical/biological: We only value the tonnes of CO2eq. that were captured/avoided as part of the project, minus the tonnes that would have been sequestered in the reference scenario anyway. For example, if a forestry project enables 10 tonnes to be captured, but in the baseline scenario, fallow land had naturally developed on the same plot and captured 4 tonnes, then only 10 - 4 = 6 carbon credits could be generated. Chapter10 on calculations in relation to the reference scenarios details this point.

Economic: For emissions reductions to be additional, it must also be proven that they would not have taken place without the valuation of carbon credits. This constraint is not taken into account by this method. This being said, economic additionality is one of the criteria that are respected in project set-ups.

Regulatory: Finally, additionality is also dependent on regulations. If it were forbidden to drive a petrol or diesel car, we could not reward the cleaner use of an electric car. Similarly, if it were compulsory to plant trees on wasteland, the planting of trees would become the reference scenario, and no carbon credit could be derived from it. This constraint is not taken into account by the present method, but is included in the project design.

4.0.3 Mesurability

It must be possible to measure/verify emissions reductions to ensure that each credit corresponds to 1 tCO2eq. avoided or captured. In the case of afforestation, reforestation or changes to forestry management methods, the tonnes of CO2eq. are directly linked to the volume of wood. It is possible to measure the volume of a tree or tree stand, either using a full inventory (the dendrometry of each tree in the plot is measured) or statistically using the permanent or non-permanent plot technique.

4.0.4 Permanence

To our knowledge, there is no formal definition of permanence in this context. Essentially, to be valid, a carbon credit must be associated with a permanent and theoretically irreversible reduction in emissions.
Since a tree has a limited lifespan, it can only be considered as a temporary, reversible carbon stock: in fact, whether dead wood is abandoned in the forest or used as timber, it will end up decomposing or being burnt, in the more or less long term. A carbon credit cannot therefore be associated with specific trees.
However, the quantity of carbon sequestered at forest level can be considered permanent. In a single sustainably managed forest, all the trees will eventually be replaced by new ones. In the event of a natural (or other) hazard putting an end to the stand in place, the reference scenario being that at the start of the project, permanence is guaranteed by non-additionality and the limit set by the Long-Term Average Stock (see chapter 5).

5 LTA Long Term Average concept

5.1 Explanation of the LTA concept

- SMLT: "Stock Moyen à Long Terme"
- LTA: Long Term Average (from Verra [Verra, 2018])

The word "average" used in this term is ambiguous. Although the calculation suggests that it is an average, because the values on which the equation is based are cumulative values (the stock of strong wood on a forest plot or, by extension, the carbon dioxide sequestered on that plot)- it is not an average. It therefore makes no sense to talk about an average.

The LTA concept is related to the concept of permanence of carbon credits. In essence, it defines the maximum theoretical value of the volume of wood on a forest plot, over an infinite time. This concept is particularly important when the wood stock fluctuates strongly, for example in the case of even-aged management (or intensive forestry) where there is a succession of forest rotations (planting, thinning, clear-cutting, etc.). In this case we have an "infinite" repetition of a pattern, the LTA represents a statistical value if it were constant. The formula would be to add up the stock of wood per year, all years from 0 to n, and divide by the number of years (i.e. n), which is infinite. We must therefore take the limit when n tends to infinity. Mathematically, this is equivalent to doing the calculation on one rotation (it is repeated identically to infinity, the number of rotations "simplifies itself").

5.2 LTA adapted to EcoTree's continuous cover sylviculture

In the case where there is no repetitive pattern, the Verra method recommends taking for the previous calculation: the value of n = the duration of the project. This is equivalent to saying, in a forestry context, that a clear cut is made at the end of the project and that we start again with an identical project, which becomes the pattern. In the remainder of this document we will refer to this method as the Verra method [Verra, 2018]. We believe that this does not adequately represent the reality of type of forest management that we practise.

Mixed continuous cover silviculture has the particularity of aiming for a stable/steady state in which all the volume extracted from the forest is replaced by natural regeneration, tending towards a stationary state. At EcoTree we model this by a series of identical patterns representing the evolution of the voume of wood between each thinning, and which is repeated ad infinitum. The LTA, in this case, is the value calculated as above for one of these patterns [1], figure 1 shows an example for Douglas Fir, figure 2 for Sessile Oak. In the remainder of this document we will refer to this method as the "infinty" method.

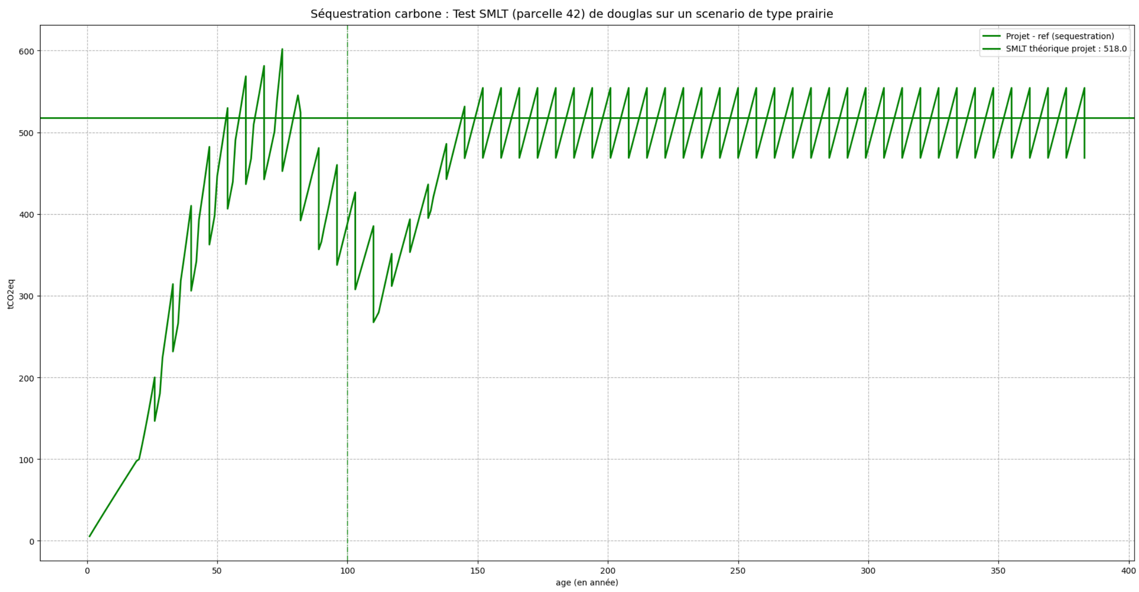

Figure 1: Example of carbon sequestration on an irregular Douglas fir itinerary for a grassland-type scenario

It should be noted that in the case of an agricultural reference scenario, the final pattern is not really stable over time. This is due to the soil carbon storage equation (see chapter 9). We still use the last pattern for the calculation, as we remain conservative in doing so, as the agricultural soil continues to slowly move towards a richer forest soil. In the same way, the case of produced stocks is more complicated because it is not really stable either but evolves slowly over time; in most cases it increases. This notwithstanding, we use the same method (i.e. we postulate that the last pattern repeats itself ad infinitum) which implies a conservative value and goes in the direction of respect for nature versus the model.[2].

[1] Our silviculture modelling leads us to define a pattern that corresponds to the volume/time function between two thinnings. If we pose this pattern as the term of a sequence, there is a certain rank N from which the difference between two terms tends towards zero. In fact, from the moment we are in the irregular zone (steady state) this difference is, by definition of the model, equal to zero, the same pattern being repeated ad infinitum. This sequence is therefore a Cauchy sequence. What's more, this modelling is carried out on $\mathbb{R}$ (the set of real numbers, of finite dimension 1), so it is a Banach space. The sequence is therefore convergent (towards a limit value, in this case the LTA). The beginning of the itinerary has no impact on the limit value, which depends only on the stationary state

[2] The half-life calculation method is already based on conservative coefficients.

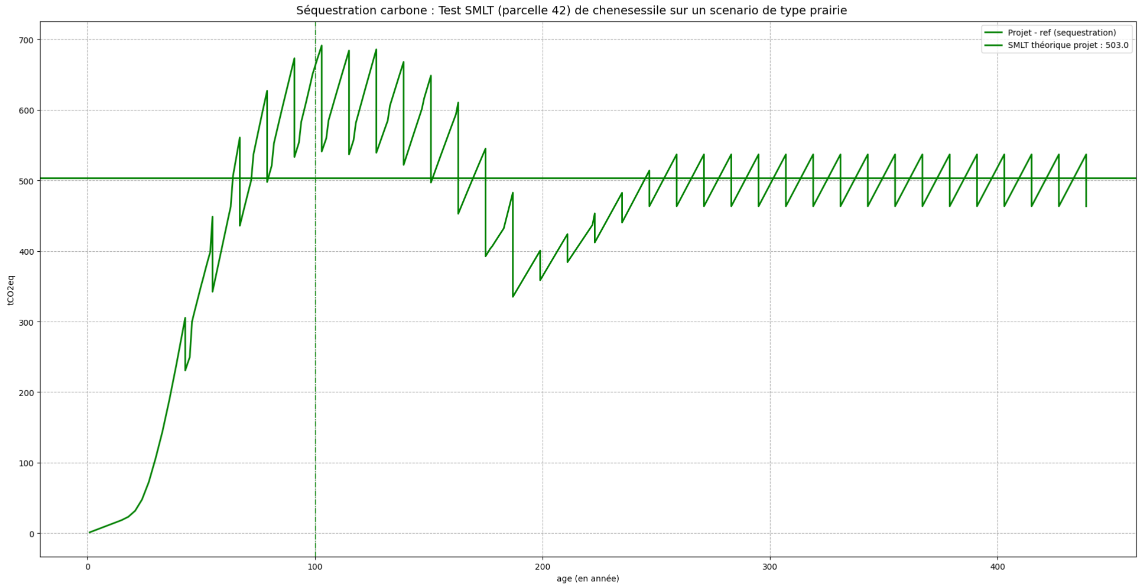

Figure 2: Example of carbon sequestration on an irregular Sessile oak itinerary for a grassland-type scenario

In the case of the reference scenarios, the values are stationary (the fallow land scenario becomes stationary after 75 years, see chapter 10), the LTA values are these stationary values, whatever the method (Verra or "infinity"). For example, for wasteland the LTA in biomass volume is 75 m3/ha.

In the interests of humility in relation to our experimental continuous cover forestry model, a discount of 10 % is applied to the calculation of the project's LTA, whether on the sequestration part or on the wood product stock part. This discount is inspired by the justification of the afforestation method of the LBC [Label Bas Carbone, 2020a] on the risks of non-permanence. However, in order to remain conservative, this discount is not applied to the LTA calculations of the reference scenarios. In this sense, the term discount should be separated from the term "buffer" which represents a way of sharing the risks by reserving a certain number of tonnes of CO2eq, here 10 % of the tonnes are simply not taken into account by the calculation for the project part.

6 Method for the creation of continuous cover forest management yield tables

The input data for any carbon calculation is based on an assessment of the biomass of the stands present on the project's forest plots. At present, there are no specific technical itineraries for continuous cover mixed species forestry (or uneven-aged forestry). EcoTree's strategy has been to use data that is as reliable and accepted as possible: the technical itineraries for each even-aged forestry species produced by the Capsis software [CIRAD, 2023] developed by CIRAD and INRAE, and the basal area values for each species observed by the AFI network (Association pour la Futaie irréguliers) and the Pro Silva association.

The challenge is to understand how to move from the values (in m3 of wood per hectare) of the Capsis itineraries given with stem modelling, to a statistical modelling of the stand in its stationary form based on the uneven-aged continuous cover forest. To do this, a method was developed, computerised by EcoTree teams and refined with independent forestry experts. The model therefore assumes a mixed plantation start. It is assumed that at least 70 % of the stand consists of the objective species, with around 20 % of a companion species with simular growth (in order to ensure species compatibility, for example, pubescent oaks and maritime pines with very different growth rates are not combined, as the oak would be totally dominated by the pine) and around 10 % of so-called biodiversity species. These percentages are indicative but seem to us to be consistent so that a technical itinerary (that of the objective species) correctly represents the stand. In the event of a mixed stand with percentages below 70 %, it would be modelled by two separate stands in proportion to the surface areas.

6.1 How it works...

- Formatting of Capsis simulation results;
- extrapolation of volume, basal area and diameter values up to the final wood categories (according to the recognised exploitable diameters);
- Calculation of growth values (annual, average) for each category of wood, if possible checking the planned date of final felling in the regular scenario;
- description of the objective values for each category of wood for the stationary part (in basal area and number of stems) and obtaining the associated statistical volumes (i.e. each category of wood is represented by its average diameter);
- creation of the wood category threshold matrix and removal rates (also by wood category);
- Calculation of the regeneration start date as a function of the age of sexual maturity, the predicted value of the rate of increase modulated by the heliophilic aspect, and the "waiting room" effect;
- Calculation of the distributions of all the wood categories over time to obtain the theoretical value around which the stand oscillates at equilibrium;
- Modification of the regular silviculture model in order to prepare the transition between itself and the stationary part;
- Creation of the transitional part using the Pro Silva method in terms of volume and total basal area;
- Calculation of the values for the initial plantation up to 10 % of the volume to preserve biodiversity trees and seeders.

6.2 Hypothesis

The whole process is purely theoretical and is subject to the variations of station and climate, so a number of assumptions need to be borne in mind (which are explained below).

- The increments calculated from the Capsis model are modulated by species to take account of the fact that regeneration takes place under cover.
- The irregularisation process is triggered (shorter time between harvesting, harvested volumes modified according to whether we are moving towards capitalisation or decapitalisation in order to reach a state of equilibrium) when the volume on the plot is equal to a value depending on the maximum volume given by Capsis and the maximum volume of the permanent stage. The trigger threshold is given by the formula :

  $$V_{déclenchement} = V_{max\_régulier} - (V_{max\_régulier} - V_{max\_stationnaire})/coefficient_{essence}$$

  where the species coefficient is a variable depending on the heliophilic aspect of said-species, plus the average and annual growth.
- The equations used to interpolate or extrapolate the various values required for modelling are chosen according to their affinity with the Capsis model: power law, polynomials of degrees two or three, exponentials, sigmoids, etc.
- The Capsis model and the AFI basal area values (figure 3 [ProSilva, 2013]) are the safeguards that limit the values of the final model.

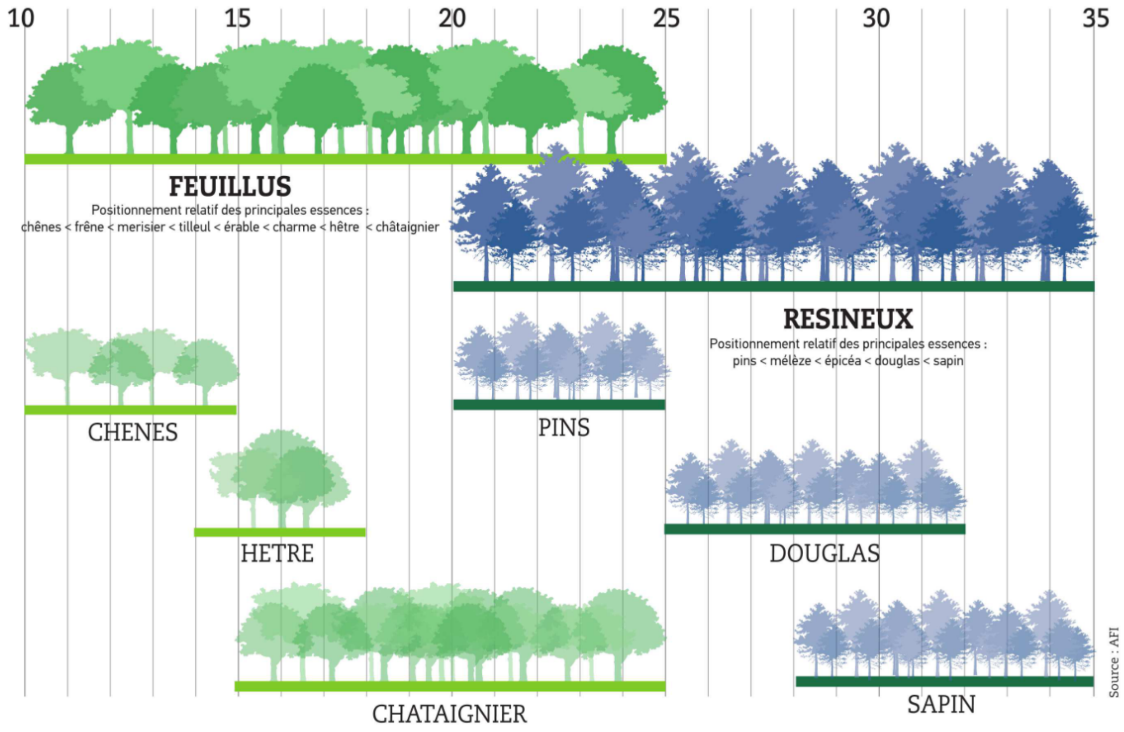

Figure 3: AFI recommendations by species, in terms of equilibrium basal area (before felling and without the understorey) [ProSilva, 2013].

6.3 Examples

Figure 4 shows the transition between the phase including the equilibrium values and the modified values of the even-aged sylviculture part, and the final phase with the transition implemented. The example chosen is Douglas fir for fertility class 2. Another example is presented for Sessile Oak, still in fertility class 2 on figure 5. The black curve represents the values given by the Capsis software, the sw, mw, lw and vlw curves represent the volumes of small wood, medium wood, large wood and very large wood respectively. The thick green curve represents the total volume, while the thin green curve represents the volume of the initial plantation.

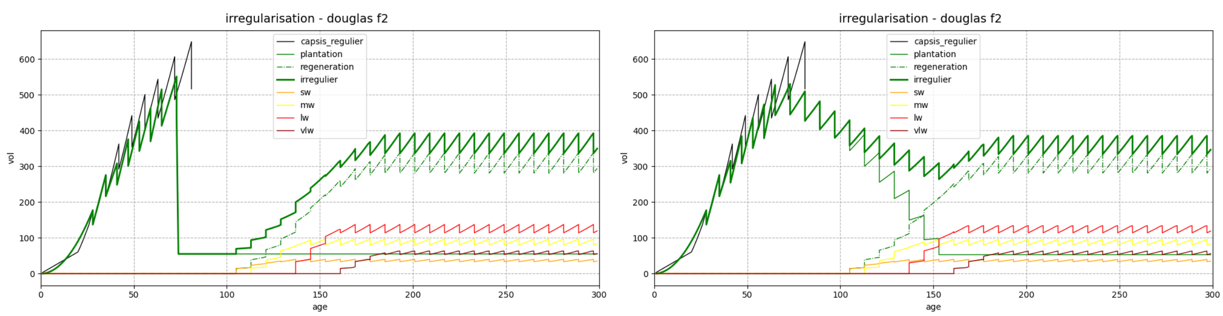

Figure 4: Steps before and after formalising the transition for Douglas fir in fertility class 2

7 Usage of the calculated values

The figures displayed by EcoTree on its carbon forecasts for forestry projects at the end of the project (at t = 100 years) are the values calculated using the LTA method, purely additional for the sequestration and wood product stock parts as well as, indicatively, the IER for the substitution part at this final date. By this is meant the said LTA "infinity" value of the carbon sequestration at the end of the project (with the 10 % discount as explained in

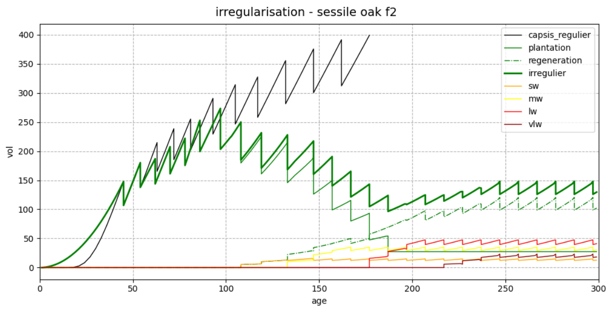

Figure 5: Final model for Sessile oak, fertility class 2

chapter 5), plus the LTA value of storage in products (idem for the discount), minus the LTA value of sequestration in the reference scenario (without the discount). This is because there is no storage in wood products for our reference scenarios (see chapter 10).

This value is preferred to the AER value, which is very conservative and does not apply to EcoTree's silvicultural strategy, which promotes long-term management through the implementation of continuous cover yield tables. EcoTree's afforestation and reforestation projects are not intended to result in clear-cutting, but to consolidate the forest heritage and biodiversity of a complete forest ecosystem. Similarly, working with living organisms on long-term projects means that EcoTree's clients must accept the inherent risks. EcoTree prepares its forest management plans taking into account, to the best of its knowledge, future hazards due to climate change with, for example, the choice of species planted and theories of ecosystem resilience as parameters.

There are three values which are calculated for each forest project:

- the value called "bilan EcoTree" corresponding to the additional carbon stock at the end of the project (i.e. $projectsequestration - baselinescenariosequestration + woodproductsstock$), projects often stop at 100 years. Known as the "100-year carbon sequestration and storage", this value is indicative.
- AERs (forest + produced stocks + total) calculated according to the LBC equations using the Verra method (i.e. over the duration of the project, i.e. most often 100 years). Denomination: **REA forest**, **REA products** and **REA total**. In cases where the end date of the project corresponds to a harvesting date, the values of sequestration and stock produced (and therefore of possible substitutions) which are used correspond to the values "before harvesting", as felling is considered to take place at the end of the year.
- the values "forest + wood product stocks + total" calculated according to the LTA method "infinity"t. Remember that the value "forest" corresponds to the additional value, i.e. the difference between the project and the reference scenario. Denomination : **LTA "infinity" forest**, **LTA "infinity" wood products**, **LTA "infinity" total**.

8 Proposed method for change in sylviculture regime

A method is presented here that meets the four criteria for carbon credits (see chapter 4) in the context of the change of management of a forest under even-aged forestry with the aim of moving towards management under mixed forestry with continuous cover. The two main criteria to be explained are additionality and permanence. Permanence is taken into account thanks to the LTA concepts (Verra and "infinity"), while for additionality it is necessary to define the reference scenario.

8.1 Additionnality

The baseline scenario is one of maintaining even-aged forestry, i.e. clear-cutting at the age of economic maturity of the stand. There is additionality only if the carbon captured by the project is greater than that captured by the reference scenario.

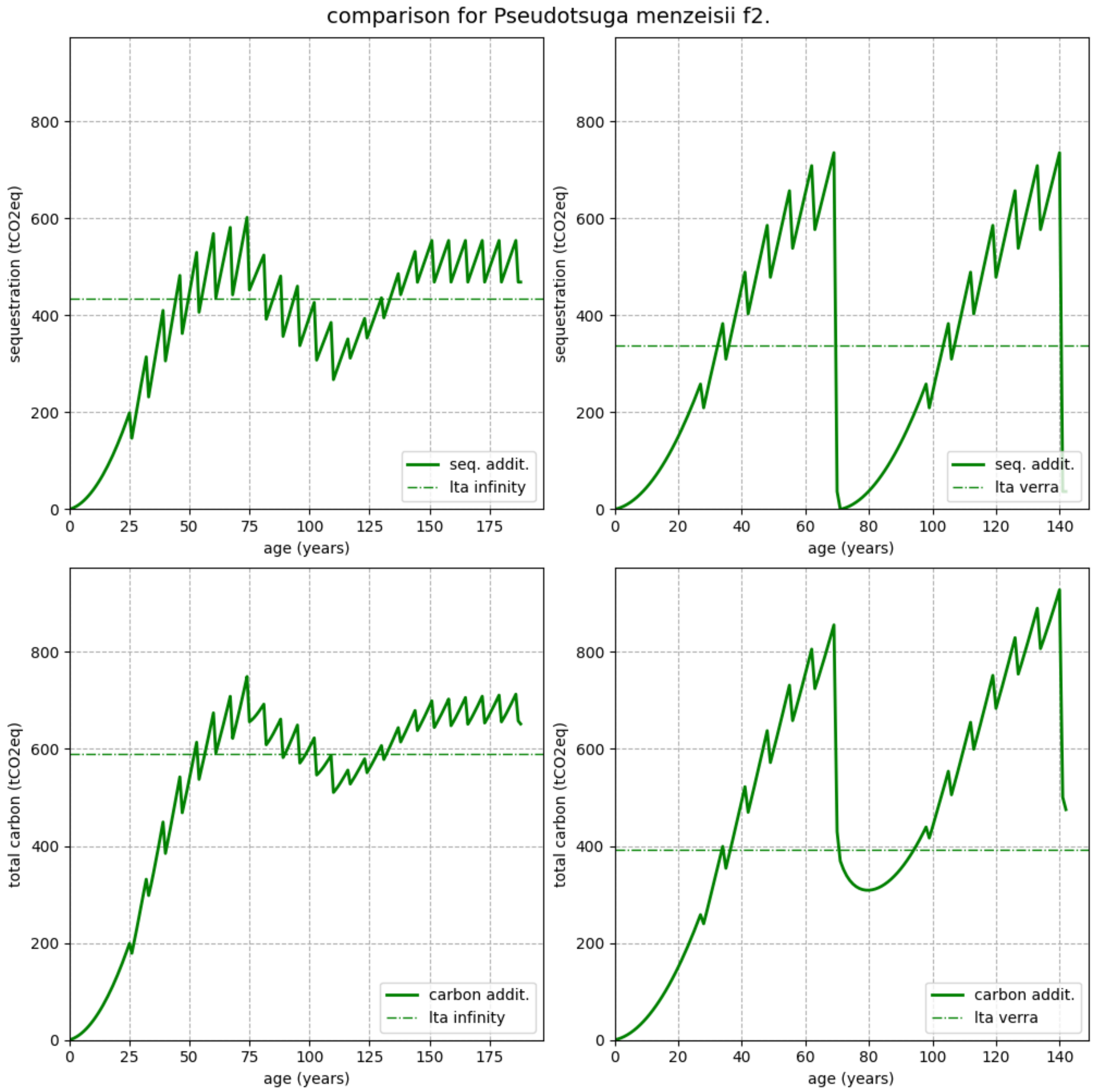

Figure 6: Example of a comparison for Douglas, fertility 2, with (top) and without (bottom) the wood products considered in the carbon calculation. The challenge is to quantify the difference between the mixed lines for each pair of graphs.

8.2 Permanence

The LTA concept only makes sense when there is either a state of equilibrium or a repetition of a global pattern in the model describing the evolution of the volume of biomass as a function of time. It is clear from the figure that this is only the case when only the sequestration part is taken into account. In fact, the impact of clear-cutting on the stock in wood products does not allow us to consider any stability or repetition of the total value of carbon. For this reason, the value chosen in terms of additional carbon is the difference in **LTA on sequestration** between the two management methods. Insofar as it seems complicated, or even unreadable, to show the difference between the two scenarios and then calculate the LTA, we have chosen to calculate the difference between the two LTAs as described above. Figure 6 shows the example of a change in management on a one-hectare plot of Douglas fir at fertility 2.

The very concept of LTA implies that the age at which management is taken over has no influence on the final result. This does not mean, however, that there are no obstacles or impossibilities to transformation on site.

9 Sequestration calculation based on LBC method, extrapolated to 100 years

At first, each compartment is calculated to find sequestration ([Gleizes, 2017, Loustau, 2004]).

total sequestration for 1 ha for each t i equal to $(ab + rb).tc + S_{soil} + S_{lit} + b_{dead}$, in dry matter tons. This result needs to be multiplied by 42/12 to obtain the final sequestration in tCO2eq.

Each coefficient is detailed as:
Aerial biomass (ab) :

$$ab = vol.exp_{aero}.infradensity$$

in dry matter tons (tDM), with:

- vol: total volume of trees for one ha at t (given by the yield tables).
- exp_{aero}: aerial expansion coefficient (i.e. for the canopy); 1,335 for coniferous and 1,611 for broadleaves.
- $infradensity$: from Label Bas Carbone [Label Bas Carbone, 2020a] or from scientific papers when the selected species is not provided in that document, for intance Thuya [CIRAD, 2012]).

Root system biomass (rb):

$$rb = e^{-1.0587+0.8836.ln(ab)+0.2840}$$

in dry matter tons (in [Label Bas Carbone, 2020a] from [Cairns et al., 1997])

Total carbon sequestration is obtained by multiplying $(ab+rb)$ by t_c (carbon ratio = 0.475 tC/tDM [Eggleston et al., 2006]).

Carbon stock in soil:
Here one needs to compare with the baseline scenario, it is considered that for agricultural land, there is a regeneration of the soil from 45 tC/ha to 70 tC/ha, following the equation:

$$S_{soil} = C_{ref} + (C_f - C_{ref}).(1 - e^{-0.0175.t})$$

from [Arrouays et al., 2002] p.161.
for fallow land or pasture, Cref = Cf and therefore Ssoil = Cref = 70 tC/ha.

Carbon stock in litter:
Label Bas Carbone proposes that balance be attained at 30 years, we therefore consider that this value is constant after that time.

$$S_{lit} = \frac{t.(L_{eq} - l_0)}{30}$$

for $t \leq 30$ years
$S_{lit} = L_{eq}$ for $t > 30$ years
with L_{eq} = carbon stock at equilibrium = 10 tC/ha.

Carbon stock in the understorey:
The understorey is considered to account for 2.4 tC/ha for hardwoods and 6.5 tC/ha for softwoods [Loustau, 2004]. These coefficients have not yet been implemented in these calculations but appear in the formalisation of irregular technical itineraries.

Carbon stock in dead wood:
In LBC this compartment in neglected, therefore $b_{dead} = 0$.
Up to the age of 30, this assumption was valid. It may no longer be valid after 100 years. EcoTree uses uneven-aged forestry management, with light but more frequent felling. In addition, out of concern for biodiversity, 3 or 4 dead trees (or "biodiversity" and regeneration are kept per hectare. For the time being, their volume is considered negligible in the context of the deadwood compartment. The aim is to keep at least 10 % of dead wood (standing or on the ground) per hectare.

10 Calculation of the carbon sequestration for baseline scenarios

In order to comply with the additionality criterion, a reference scenario must be selected. This is because only emission reductions that go beyond this baseline scenario are recognised under the Low Carbon Label (III.C.1).
There are three baseline scenarios (calculated for every t in the lifetime of the project): reclaiming agricultural land, reclaiming grassland or grazing land and reclaiming fallow land. In the case where the project is the aforestation of a clear cut that has not been reconstituted or following an emergency cut for health reasons (associated with supporting documents), the reference scenario selected is "resumption of fallow land".

10.1 Recovery of agricultural land:

There is no accumulation of biomass, the chosen value is 5 tC/ha as a constant.
Soil stock: 45 tC/ha.
There is no litter as there is no tree or shrub on the land.

10.2 Recovery of pasture/grazing land:

There is no accumulation of biomass, the chosen value is 0 tC/ha as a constant.
Soil stock: 70 tC/ha.
There is no litter as there is no tree or shrub on the land.

10.3 Afforestation of a fallow land:

It is considered that there is an increase in biomass of1 m^3/ha/year by starting on an empty plot (grazing or clear-cutting). Over a period of 30 years in the Low Carbon Label, the reference scenario would remain exclusively fallow land [Label Bas Carbone, 2020a, Label Bas Carbone, 2020b]. Here, over long projects (100 years and more), ecological succession will already have had time to take place, so the wasteland gradually becomes a forest. The increase of 1 m^3/ha/year remains consistent. However, the increments of 1 m^3/ha/year are stopped at 75 years and then continue at this stationary value of 75 m^3/ha. According to experts, this is a reasonable value. In fact, it seems likely that after 75 years we will have a stable poor coppice type forest, especially if it is regularly used to obtain firewood from pioneer species, as the method stipulates when it assumes that no wood products (calculation of the AER produced from LBC) other than firewood are harvested in this reference scenario. Therefore, for the wood products compartment, following the example of the Label Bas Carbone, we separate hardwood wasteland (firewood, therefore no wood products in the calculation), and softwood wasteland (pulpwood, called YL in this method).
For the aerial expansion coefficient we use an average of the hardwood/softwood coefficients (i.e. 1.611 and 1.335 respectively).
We use the previous formulas for calculating biomass with a constant initial soil storage of 70 tC/ha (either pasture land that is becoming overgrown, or a clear cut, which therefore has a forest floor). For the stock in the litter, the formula used is that adapted to 100 years as previously, in fact we consider that the litter is either non-existent or very damaged at the beginning of the project.

10.4 Change in forest management

The reference scenario is even-aged forestry management, and the carbon calculation follows the same procedure as in the project, the difference lying in the technical itinerary used. We use the Capsis simulations as input data, for the same species and fertility classes. Calculations are made only for the sequestration compartment.

11 Calculation of carbon stocked in the wood products

Depending on the average diameter of the stems harvested, several product categories are differentiated. The quantities of carbon stored in them and the length of time they remain in storage depend upon this:

- T = carbon stock of wood products intended for sawing (timber),

– YL = carbon stock of wood products intended for industry. Two sub-categories can be distinguished: wood for paper pulp (PW = 44 % of YL), panels (PaW = 56 % of YL),
– FW = carbon stock of wood products used for wood energy. No AER is taken into account for FW.

The following calculation method is implemented to determine the quantity of carbon in the products at time t: the carbon (tCO2e) extracted during the years of cutting is calculated, by separating the volume of wood into yard lumber (YL) and timber (T); the percentages of quality wood by species come from the work of Cemagref-IFN, adapted for the LBC [Ginistry et al., 2009, Label Bas Carbone, 2020a]. We have currently implemented a version of these wood quality percentages by species taken from the IFN quality assumptions (cf. Annex 1, page 19)); these percentages already take into account the 50 % of timber that goes to fuelwood due to sawing yield ([Label Bas Carbone, 2020a].

11.1 Degradation calculation with half-life:

Pour les années entre les coupes, nous calculons la dégradation du stockage de CO_2 équivalent (équation de demi-vies selon le type : BI = 25 ans, BO = 35 ans, BP = 2 ans ; voir figure 7) des coupes précédentes.
For the years between cuts, we calculate the degradation of the storage of CO2 equivalent (equation of half-life according to the type: YL = 25 years, T = 35 years, PW = 2 years; see figure 7) of the previous sections.

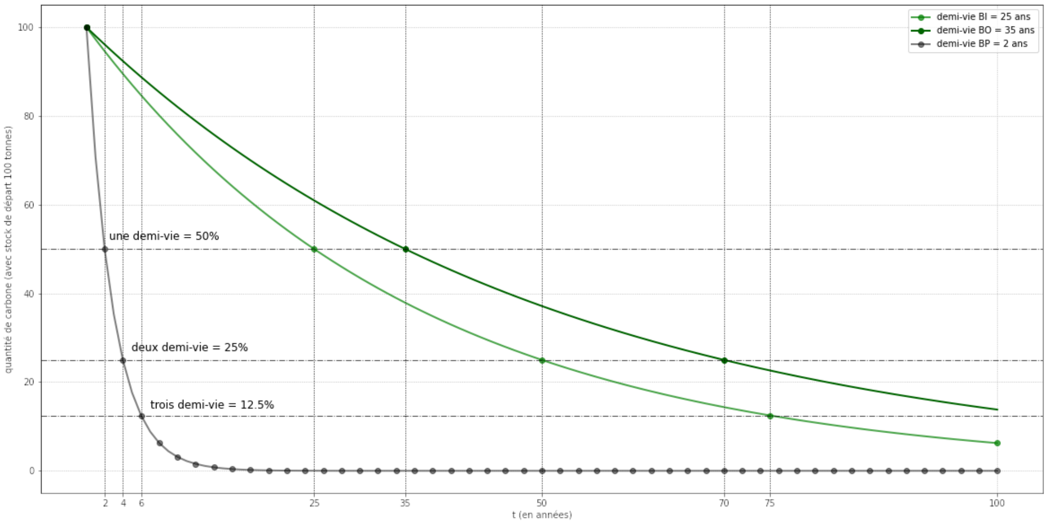

Figure 7: Half-lives for the different classes of wood products; in the case of timber, the carbon stock is halved every 35 years, corresponding to its half-life

.

This is calculated for each cut by:

$$C(n+1) = C(n).e^{-k} \text{ with } k = \frac{\ln(2)}{t_{half}} \text{ [Pingoud and Wagner, 2006].}$$

For harvest years, we add the various percentages to the wood quality stocks. Since harvesting takes place at the end of the year, we do not take into account the degradation of the stocks added during the year of harvesting, but rather the degradation of all the stocks in the wood products from previous years. In each year t we therefore count the total stock of carbon (in this case CO2eq.) stored individually in the different types of wood products: FW, PW, YL and T.

12 Substitution effects

Substitution concerns the different product categories: FW, YL and T. The following coefficients [Label Bas Carbone, 2020a] are used. At 100 years, distinctions are permitted, whereas at 30 years few clearings are taken into account and average FW or YL coefficients are used:

- T = 1.52
- YL = 0 for paper (PW = 44 % of YL), 0.77 for panels (FWa = 56 % of YL)
- FW = 0.25

This involves multiplying the volume of wood in cubic metres extracted during thinning by the substitution coefficients [Rüter et al., 2016], taking into account the percentages of wood quality and sawmill by-products. The calculation is carried out cumulatively for each cut. It is consistent to consider these substitution effects as cumulative and definitive in order to obtain an overall final figure. In the same way, "the curve has a particular shape with levels corresponding to a threshold of avoided emissions for each thinning carried out, which makes it possible to mobilise additional wood for construction purposes, for example." [Gleizes, 2017]

13 Calcul des Réductions d'Emissions Anticipées (REA) générables du fait de la séquestration du carbone par l'écosystème forestier

The AER are always calculated in relation to a reference scenario and over the entire duration of the project. To calculate them, the minimum must be sought between:

- the difference between the storage in the forest ecosystem of the project and the storage of the reference scenario at the end of the project (100 years).
- the difference in Medium Long-Term Stocks (MLTS) over the duration of the project.

$$REA_{foret} = \min(\Delta S(100), \frac{1}{R}.\sum_{n=0}^{R} S_{projet}(n) - \frac{1}{R'}.\sum_{n=0}^{R'} S_{ref}(n))$$

with:

- $\Delta S(100)$: difference in carbon sequestration in year 100 between the project scenario and the reference scenario (in tCO2e),
- Sproject: carbon sequestration in the forest compartments of the project scenario (in tCO2e),
- Sref: carbon sequestration in the compartments of the reference scenario, (in tCO2e),
- R: rotation duration of the project species,
- R ': rotation duration of the reference scenario. If the age of exploitability of the increments is not known, we will apply the same age as for the project scenario, therefore R = R '.

14 CComputation of AER that can be generated due to carbon storage in wood industry products

As with the AERs generated by sequestration, these AERs due to carbon storage in wood products are calculated at the end of the project.
The value is calculated according to the formula below, over the life of the project (100 years). The differences in carbon storage in wood products between the project and the baseline scenario are used. In cases where agricultural land or grassland/pasture is taken over, there is no wood product. The formula for the REA produced is as follows :

$$REA_{products} = \frac{1}{100}.\sum_{n=0}^{100}(C_{project}(n) - C_{ref}(n))$$

with:

- $C_{project}$: carbon stock in wood products that would be harvested in the project scenario (in tCO2eq),
- C_{ref}: carbon stock in wood products that would be harvested in the reference scenario (in tCO2eq).

15 Computation of Indirect Emission Reductions (IER) that can be generated

They are also calculated at the end of the project. This time, the cumulative difference in carbon storage in wood products between the project and the baseline scenario is calculated over the life of the project (100 years).

$$IER = CS.\frac{1}{100}.\sum_{n=0}^{100}(Flux_{project}(n) - Flux_{ref}(n))$$

with:

- $Flux_{project}$: volume of wood in wood products that would be harvested in the project scenario (in m^3), by type of wood product,
- $Flux_{ref}$: volume of wood in wood products that would be harvested in the reference scenario (in m^3), for the same reasons as above, in the case of fallow land and by type of species (hardwood or softwood): the coefficient for hardwood is that for fuelwood, that for hardwood is that for industrial wood [Label Bas Carbone, 2020a]
- CS: substitution coefficients

We consider that these figures are purely indicative and cannot be used other than as a means of communication/education to change consumption practices, etc. They are therefore not added to the AER as in the Label Bas Carbone method.

16 Limits

EcoTree nevertheless draws everyone's attention to the fact:

- that seeing as the living world is by definition difficult to quantify, this carbon captation methodology is in itself an estimate and by no means a perfect and just measure, for the following reasons:
  - (i) it is based on our methodology for forestry management plans, a new methodology for resilient forests, theoretically correct, but that the living world and natural hazards (notably global warming) might change;
  - (ii) it is made ex-ante, in other words this estimation stems from a forward-looking assessment of forests and their carbon sequestration. Thus, it allows us to frame the carbon sinks that the forest will likely create during the cycle in question;
  - (iii) hence, figures are rounded to the CO2 equivalent tonne;
  - (iv) furthermore, an ex-post measure made by EcoTree and its teams will enable us to make the effective carbon capture more precise, year after year.
- That any action aiming to contribute to the creation of carbon sinks only makes sense if it's part of a more global approach, including avoidance and reduction,
- that getting involved with forestry solely for its carbon sequestration and storage capacity could encourage the development of management that is not sustainable or respectful of the environment and its biodiversity.

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18 Annexes

18.1 Annex 1 — Percentages of different qualities of wood

We select these percentages according to the diameters (according to the IFN), data modified to take into account the assumptions of the Label Bas Carbone (50 % of sawn wood lost, spent in FW).
Note: the french terms for wood products categories are used in the following table.

https://inventaire-forestier.ign.fr/IMG/pdf/rapport_biomasse-2009vf.pdf

Données modifiées pour prendre en compte les hypothèses du LBC (50% des sciages de BO perdu en BE)

CHENE

Dg (cm)	BE	BI	BO
< 27,5	0%	100%	0%
[27,5 - 47,5[	35%	30%	35%
≥ 47,5	45%	10%	45%

SAPIN + EPICEA COMMUN

Dg (cm)	BE	BI	BO
< 22,5	5%	90%	5%
≥ 22,5	40%	20%	40%

HETRE

Dg (cm)	BE	BI	BO
< 27,5	0%	100%	0%
[27,5 - 47,5[	30%	40%	30%
≥ 47,5	45%	10%	45%

PIN SYLVESTRE + PIN MARITIME + AUTRES RESINEUX

Dg (cm)	BE	BI	BO
< 22,5	0%	100%	0%
≥ 22,5	35%	30%	35%

AUTRES FEUILLUS

	BE	BI	BO
∀ Dg	25%	50%	25%

18.2 Annex 2 — Method evolution

The EcoTree methodology is now in its third major version, here is a reminder of the main steps:

- Version 1 — adaptation of the Low Carbon Label to EcoTree's 100-year forestry projects.
- Version 2.x — updated from version 2 to include aerial expansion and infradensity coefficients for species not available in the official Low Carbon Label document.
- Version 3 (current version) — added part on permanence clause and explanations on LTA and LTAS concepts, changed duration before stabilisation for wasteland scenario, created "LTA infinity" metric
- Version 4 (current version) — Revision to present the method for creating silvicultural itineraries and focus on adapting the method to the fundamental criteria for carbon credits. Addition of a proposed method for changing silvicultural management (regular to irregular). Addition of appendix 3 specifying the validation procedure.

18.3 Annex 3 — Bureau Veritas' validation procedure

This appendix details the technical points for verification of carbon calculations by Bureau Veritas: tolerated deviations, elements to be transmitted to validate admissibility, the list of metrics to be verified, etc.

- Elements to be transmitted:
  - An Excel file with the itinerary for each plot in the forest (a forest is made up of one or more plots, each of which has a technical itinerary (species + fertility class), a surface area and a baseline scenario).
  - A certificate from a forestry expert for the entire forest (if certain plots are not eligible for additional carbon, this will be clearly stated on the certificate).
  - A text or csv file containing the results of the calculations made by EcoTree (see below for details of the metrics calculated for verification).
  - An order form (with a maximum of five (5) forests to be verified per shipment).

- Elements that must appear on the certificate in order to check that they match the Excel files provided for each plot: species and fertility class, year of thinning, volume before and after felling, thinning volume. An economic column also appears because the expert also gives an opinion on these values: surface area, reference scenario. Each certificate includes a conclusion from the expert on the soundness of the proposed itineraries.
- When differences are noted between the values calculated by EcoTree and Bureau Veritas: if Bureau Veritas finds a value of less than 5 tCO_2eq. higher than that of EcoTree, use the EcoTree value; if Bureau Veritas finds a value of more than 5 tCO_2eq. higher than that of EcoTree, repeat the verification; if Bureau Veritas finds a value lower than that of EcoTree and the difference does not exceed 5 tCO_2eq. higher than that of EcoTree, repeat the verification; if Bureau Veritas finds a value lower than that of EcoTree and the difference does not exceed 5 tCO_2eq., the Bureau Veritas value is selected; if Bureau Veritas finds a value lower than that of EcoTree which exceeds 5 tCO_2eq., repeat the check.
- The final values appearing on the certificate are rounded to the nearest tonne of carbon dioxide equivalent (tCO_2eq.).
- List of metrics used to compare calculations:
  - Calculation of additional carbon sequestration and storage (tCO_2eq.) (with details: Sequestration of the project (tCO_2eq.), Sequestration of the reference scenario (tCO_2eq.), Stock in wood products (tCO_2eq.))
  - Forest AER calculation (tCO_2eq.) (with details: LTA, DeltaStock at 100 years),
  - Calculation AER products (tCO_2eq.) (idem with details),
  - Total AER calculation (tCO_2eq.),
  - Calculation of substitution effects (tCO_2eq.) = total IER
  - Calculation LTA "infinity" forest (tCO_2eq.) (with details: LTA "infinity" of the project, LTA "infinity" of the reference scenario)
  - Calculation LTA "infinity" products (tCO_2eq.)
  - LTA calculation "infinity" total (tCO_2eq.) = LTA inf
  - — Caution — when calculating the "infinity" values, the tenth pattern from the volume stabilisation on the steady state part of the route is used.
- The metrics appearing on the Bureau Veritas certificate are as follows (with details by plot):
  (i) Additional carbon sequestration and storage over 100 years
  (ii) Total Anticipated Emission Reductions (AERs) that can be generated over 100 years
  (iii) Total generatable Indirect Emission Reductions (IERs) over 100 years
  (iv) LTA "infinity" total
- Please note that the verification certificate will be sent within fifteen (15) days from the date of validation of admissibility.