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Article

Integrated climate project and carbon sequestration: From tree plantation to long-term wood deposition

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Abstract: To achieve the Paris Agreement's temperature goal, greenhouse gas emissions should be reduced as soon as, and by as much, as possible. By mid-century, CO_2 emissions would need to be cut to zero, and total greenhouse gases would need to be net zero just after mid-century. Achieving carbon neutrality is impossible without carbon dioxide removal from the atmosphere through afforestation/reforestation. It is necessary to ensure carbon storage for a period of 100 years or more. The study focuses on the theoretical feasibility of an integrated climate project involving carbon storage, emissions reduction and sequestration through the systemic implementation of plantation forestry of fast-growing eucalyptus species in Brazil, the production of long-life wood building materials and their deposition. The project defines two performance indicators: a) emission reduction units; and b) financial costs. We identified the baseline scenarios for each stage of the potential climate project and developed different trajectory options for the project scenario. Possible negative environmental and reputational effects as well as leakages outside of the project design were considered. Over 7 years of the plantation life cycle, the total CO_2 sequestration is expected to reach 403 $tCO_2 \cdot ha^{-1}$. As a part of the project, we proposed to recycle or deposit for a long term the most part of the unused wood residues that account for 30% of total phytomass. The full project cycle can ensure that up to 95% of the carbon emissions from the grown wood will be sustainably avoided.

Keywords: sustainable climate project; forestry; carbon storage; greenhouse gases; emission reductions; economic valuation; long-term carbon sequestration

1. Introduction

The adverse impacts of climate change have by now already affected all the countries on all continents [1,2]. Planned and implemented mitigation measures need to be significantly strengthened to keep the global temperature rise within 1.5–2.0 °C above the pre-industrial era, as stated in the goals of the Paris Agreement [3].

Countries are off track to achieve even the globally highly insufficient Nationally Determined Contributions (NDCs) [4]. Pathways following the current NDCs until 2030 reach annual emissions of 47–57 Gt $CO_2eq \cdot yr^{-1}$ by 2030, thereby making it impossible to limit warming to 1.5 °C (> 50%) with no or limited overshoot and strongly increasing the challenge of limiting the warming to 2 °C (> 67%) (high confidence) [5]. This assumes full implementation of the unconditional NDCs and implies a 66% chance of staying below the stated temperature limit. If, in addition, the conditional NDCs are fully implemented, each of these gaps is reduced by about 3 Gt CO_2eq [4].

To achieve the global goal of the Paris Agreement, the involvement of businesses in all spheres of economic activity is necessary in addition to the efforts of government agencies and public organizations [6]. To engage companies in climate projects, such activities as self-sufficient businesses that create added value and that are not directly related to climate but have meaningful mitigation and offsetting effects need to be implemented. If, however, business climate action is only a response to tax incentives, coercion, or charity, it cannot be considered sustainable, as the primary source of taxes or grants is still the value added from the core business [7].

Agriculture, forestry, and other land use (AFOLU) mitigation options, when sustainably implemented, can deliver large-scale greenhouse gas (GHG) emission reductions and enhanced removals but cannot fully compensate for delayed action in other sectors. In addition, sustainably sourced agricultural and forest products can be used instead of more GHG-intensive products in other sectors [5].

Forests are among the most productive ecosystems in the world [8]. However, rapid carbon storage as biomass (up to 8 $t \cdot ha^{-1} \cdot yr^{-1}$ at temperate latitudes [9]) occurs precisely in young forests (up to 15–20 years old). The maximum current increment of slow-growing conifers occurs at a later age (30–50 years), and the maximum current increment of birch is at 15–30 years [10,11]. In addition, stored carbon is released into the atmosphere during forest fires and timber harvesting [12,13].

For fast-growing species such as eucalyptus productivity can vary considerably (ranging from 17 to 50 $t \cdot ha^{-1} \cdot yr^{-1}$), depending on the site’s forest conditions and Eucalyptus species [14]. To achieve the high sequestration rate, it is necessary to cut forest plantations periodically (every 7–20 years, depending on the species) for lumber and make replanting on the empty land area to regenerate young forest and reproduce future cycles.

In order to ensure long-term carbon storage, it is necessary to plan the further cycle of wood use: when processed into products, it should not burn or rot for at least 30–50 years. Consequently, there is a requirement to ensure a long life cycle for wood products, including their recycling. For example, the recycling of wood into paper does not fulfill the criteria of long-term preservation: even with recycling, the lifespan of paper products is 2–3 years, after which the waste material is incinerated or rots in landfills [15].

For wood materials to be used as a storage of carbon, they must not be easily combustible and biodegradable (bio- and fire-resistant). The requirement applies only to recycled wood materials regardless of the application. The greatest potential in this context can be long-life products or materials, such as building structures [16].

Considering the above-mentioned assumptions and a goal to maximize carbon sequestration, the following idea of linking the use of wood in construction and the plantation cultivation of the required wood species becomes promising:

- Regularly renewable plantation forest, on the one hand, replaces the clearing of wild old-growth forests, contributing to biodiversity conservation [17] and other ecosystem services [18];
- The use of wood in construction has a multiplier effect in reducing greenhouse gas emissions: plantation wood in building structures not only stores carbon (up to 100 years), but also replaces carbon-intensive cement and steel (potentially

from 30% to 50% of cement and steel production could be substituted with wood-based materials) [19,20];

- Waste arising from the wood processing stage is a renewable fuel and can replace fossil fuels (e.g., coal) [21].

Thus, vertical integration of related industries "plantation forestry—manufacturing of long-life wood-based materials—building structures with the highest possible proportion of wood-based materials" can ensure large-scale sequestration of atmospheric carbon.

Another promising and effective way of long-term carbon storage in wood products is recycling and reuse. In this case, furniture and other products are considered products that may have a life span of 7–20 years or more. For example, Kronospan[1] offers to collect end-of-life products from users and carry out up to 8 recycling cycles. In this case, the carbon storage period of the products will cumulatively exceed 100 years [22].

Wood treated against decay and fire is extremely resilient: it is unsuitable for burning as fossil fuel and difficult to recycle [23]. To reduce emissions, it is advisable to prevent its conversion to waste and decomposition in landfills.

A theoretical solution to this problem could be to submerge wood residues in the ocean to a depth of more than 1 km. In conditions of low temperatures and high pressure, the decomposition process of wood will be significantly slowed down, and buoyancy will be lost. At the same time, if the decomposition process goes on for 100 years or more, this may be considered as long-term storage of wood and prevention of emissions [24].

The purpose of this paper is to analyze the feasibility and sustainability of the proposed stages of carbon storage, processing and sequestration, starting from forest plantation through processing and utilization to long-term storage. Two performance indicators are considered: a) Units of emission reduction (because of the proposed stages, a significant part of the carbon stored in the plantation will not serve as a source of emissions for more than 100 years); b) financial costs—the activity at each stage should be profitable.

Eucalyptus plantation cultivation in Brazil was chosen as the theoretical ground for the hypothesis testing, as it provides the fastest growth of quality wood under current conditions [25], suitable for further processing into long-life products.

2. Materials and methods

Considering that the project is to be implemented in Brazil, the methodological approaches outlined in the Guidelines for National Greenhouse Gas Inventories [25] were used to estimate emissions and removals from the baseline and project activities. In addition, climate project methodologies endorsed by Verra [26] were reviewed, and available scientific studies and publications on similar topics were analyzed.

The Database of the Department for Business, Energy & Industrial Strategy (DBEIS) and the Department for Environment, Food and Rural Affairs [27] was chosen as the source of data for conversion emission factors for transport leakage estimates under the project activity options. According to the DBEIS guidance document [28], the development of the factors considers the main recommendations of the Guidelines [29]. GHG emissions per unit of cargo turnover were assumed to be the same for all stages of the climate project by mode of transport: road transport (timber truck)—0.07274 kg CO_2 $t^{-1}\cdot km^{-1}$ (100% vehicle load), marine transport—0.01305 kg CO_2 $t^{-1}\cdot km^{-1}$ (average class of a cargo ship with deadweight of 10,000–25,000 thousand t).

Cost-benefit analysis was used as a method of economic evaluation of the project [30], which identified the main costs and sources of profit of the project. Current data from several studies on eucalyptus planting in Brazil were used to identify the main cost sources [31].

3. Results

3.1. Climate project concept

To analyze the feasibility of the project, the authors sequentially reviewed and separately assessed the interrelated stages of the climate project:

- Plantation forestry;
- Eucalyptus utilization (in Brazil);
- Long-term deposit of wood residues.

Based on the available data, emissions, removals and potential GHG emission reductions were calculated for different options of baseline and project scenario for each interrelated stage. Additionally, an economic assessment of the implementation of the climate project stages was made.

3.2. Plantation forestry

Baseline. To form the scenario that best represents the conditions to occur in the absence of the project (baseline scenario), we studied Brazilian forest plantations (observed in 2019 near Jacarei, the state of Sao Paulo), the main species of trees planted, productivity, biotechnologies used, biotic and abiotic factors affecting eucalyptus growth rate, geographical features of Brazilian regions, soil types, and the spatial location of existing eucalyptus plantations [32–36].

Depending on the forest conditions and the variety of eucalyptus, productivity can vary considerably. Eucalyptus planting densities vary between 1400 and 7000 trees per hectare, with annual wood growth ranging from 17 to 50 $t\cdot ha^{-1}\cdot yr^{-1}$ [13].

We assume that, on average, a profitable plantation with existing technology produces 50 m^3 of wood per hectare annually. We will also assume an average wood density of around 500 $kg\cdot m^{-3}$ [37]. The plantation then produces an average of 25 t of wood per hectare annually, which is consistent with source [13].

The carbon content of dry wood is 49%–50% of the mass. Since the shrinkage factor for Eucalyptus is quite high, we assume a carbon content of 40% in the raw wood. This yields 10 t of carbon per hectare per year, or 36.64 t of stored CO_2. Calculations are approximate and do not consider carbon stored in branches, roots and leaves. Tables similar to [38] and the Guidelines [29] will be needed for further refinement.

The assumptions underlying the baseline are summarized in **Figure 1**.

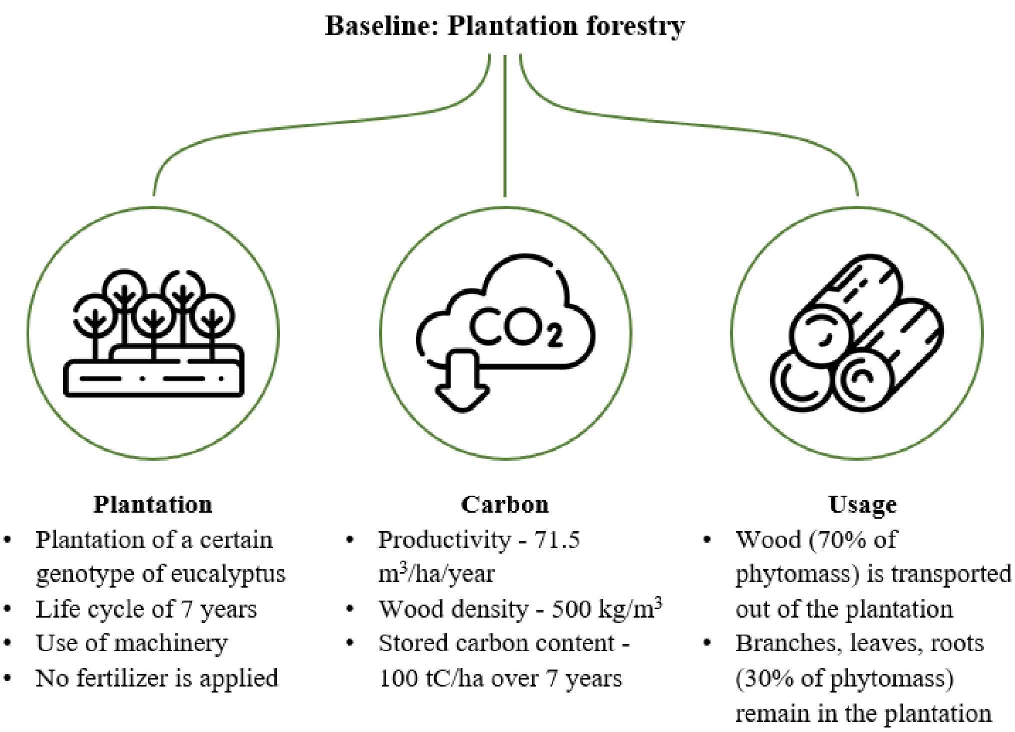

Figure 1. Basic parameters and assumptions for the plantation forestry baseline.

Project scenario. Without the implementation of the climate project, there would be no additional investments and technology improvements for the existing plantation in the baseline.

Schematically, the steps of one cycle with the proposed improvements for the project plantation are shown in the diagram of **Figure 2**. The model of the project scenario of plantation forestry is shown in **Figure 3**.

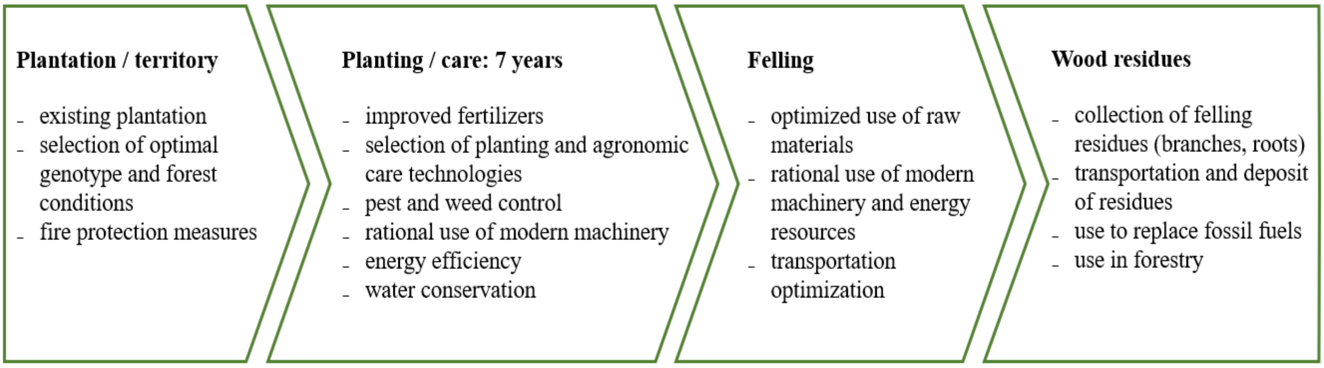

Figure 2. Schematic diagram of one cycle of the project plantation.

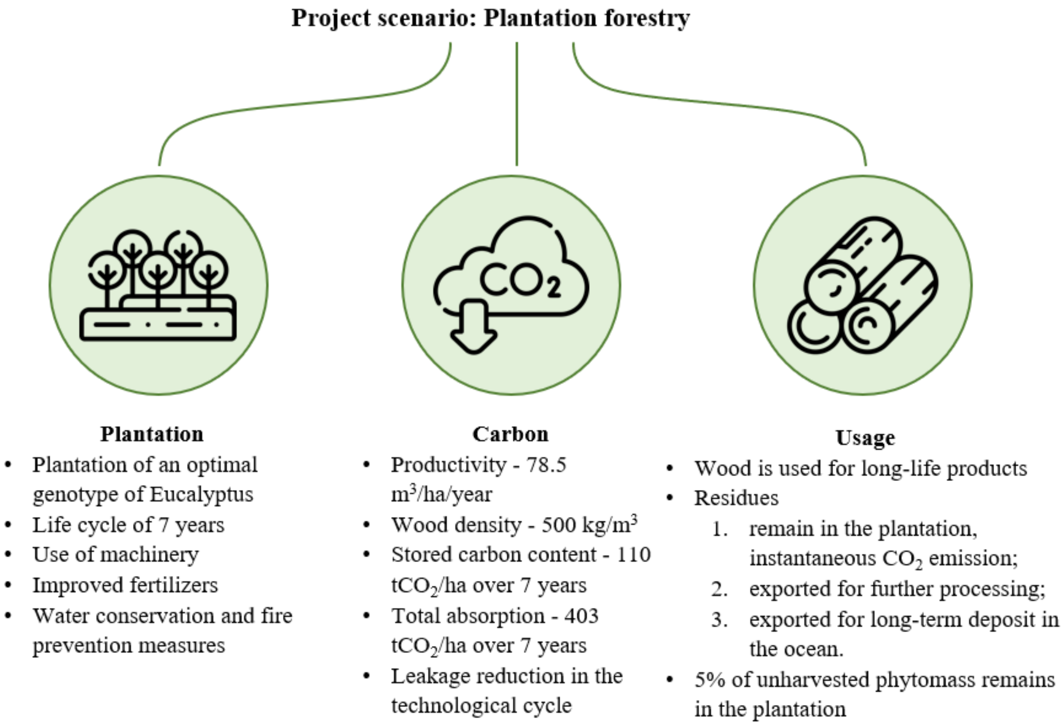

Figure 3. Model of the plantation forestry project scenario.

To develop the baseline, project scenarios and assumptions, we took into account information from [39–41], as well as the requirements of the Verified Carbon Standard (VCS) greenhouse gas emission crediting program, and implemented climate projects with similar ideas [42–44], in addition to the above-mentioned literature and internet sources.

3.3. Eucalyptus utilization in Brazil

The wood of fast-growing species, especially eucalyptus, is gaining more prestige and popularity. Modern technologies are developed to produce high-quality cellulose from eucalyptus wood, and new species are introduced to increase the efficiency of plantation farming. Eucalyptus plantations already provide up to 30% of the world's pulp production, and after the launch of new plants in South America, their share could be more than 40% [45].

Baseline. To assess the baseline scenario, we studied the leading industries in Brazil that use eucalyptus as a raw material, the main properties of the wood, the types of materials made from eucalyptus, and the types and demand for finished products.

Brazil is the global leader in eucalyptus pulp production, accounting for approximately 3/5 of world production. The main consumption region for Brazilian pulp is Europe, which accounted for 52% of foreign shipments in 2008. Brazil is the best place for eucalyptus plantation farming due to climatic conditions and scientific progress in forestry. Stand productivity in Brazil averages 41 $m^3 \cdot ha^{-1} \cdot yr^{-1}$, which is higher than Australia (25 m^3) [33,45].

Drying eucalyptus timber is difficult because wood is prone to cracking and warping. Eucalyptus is a very drying species. Shrinkage (swelling) coefficients are in the radial direction—0.21%–0.29% and in the tangential direction—0.31%–0.4%. Plantation wood shrinks 10%–15% less than wood of natural origin. The stability of the shape and dimensions of well-dried eucalyptus wood is high. One of the most valuable qualities of eucalyptus wood is its high biostability, as the material is virtually unaffected by fungi and insects [46].

The main advantage of eucalyptus is its fast growth and the suitability of its wood as a raw material for the pulp and paper industry. The production of biofuels (wood pellets) is the second consumer of eucalyptus wood in Brazil after paper production. Genetically modified species and clones are preferred [47].

The assumptions underlying the estimated baseline are summarized as follows:

- Available grown wood raw material—350 $m^3 \cdot ha^{-1}$ in 7 years;
- Use of raw materials—production of paper and wood pellets (short-life products);
- The average distance for transporting timber from forest producers is 100 km;
- It is assumed that the baseline scenario may include processes such as transport, waste production, energy inputs and other possible emission sources (clarification required);
- Depending on the supply chain adopted, it may be necessary to include transport, selling, storage and warehousing in the calculation, as leakage may occur at each stage. Only emissions from timber transport are included in the baseline calculations.

Information from sources [42,46,48–50] was considered.

Project scenario. Without the implementation of the climate project, the eucalyptus raw material utilization chains described above would exist. The project scenario involves modifications to the baseline, which can be summarized as follows:

- Utilization of residues (other wood fractions) for the production of biochar and biofuels;
- Changing supply chains towards the production of goods:

Option 1—long-life goods of 100 years or more (timber/round timber);

Option 2—goods with an average life of 20 years or more (planks, building materials and chipboard) using technology for collecting end-of-life products and recycling them (e.g., Kronospan);

- Replacement of materials with high carbon capacity: iron, concrete, etc.

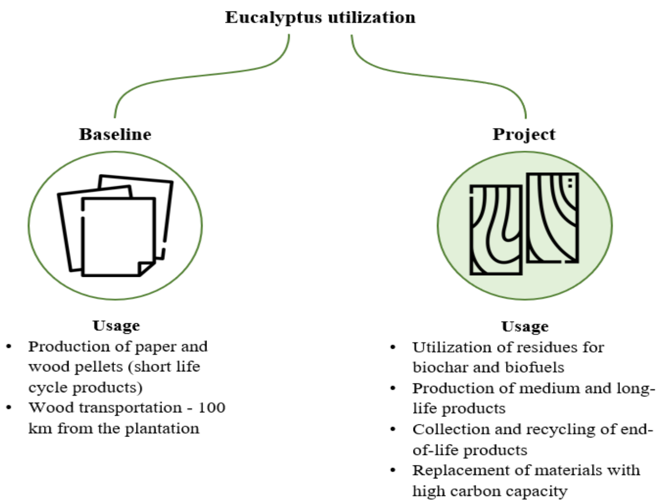

Figure 4. Schematic diagram of the basic and project activity scenarios for the eucalyptus utilization stage.

Considered supply chains in the baseline and project scenarios are summarized in **Figure 4**.

Thus, after the plantation forestry project stage, the production of long-life wood products is considered, which will not only increase the project's carbon units, but will also serve as proof of permanence.

However, there is a high risk of market leakage, which will occur if project activities significantly reduce the production of a commodity and cause a change in the equilibrium of supply and market demand, leading to a shift in production to another location. In such a case, the number of carbon units will be significantly reduced, and the overall positive effect of the project will not be achieved.

3.4. Long-term deposit of wood residues

Baseline scenario. All wood waste, from tree planting to end-of-life products, is incinerated or decomposed. In the case of using wood for products with a short life cycle, an assumption can be made that all the carbon stored by the eucalyptus plantation is emitted in the year of felling. This corresponds to the VCS [43] standard for the AFOLU sector.

For the project activity, the unutilized share of phytomass (30%, [51]) remains in the plantation, all stored carbon is emitted to the atmosphere, i.e., the baseline is zero.

Project scenario. The project activity proposes a fundamentally different approach. Wood and wood products that cannot be recycled and used as products are collected, packaged and submerged in the deep ocean where low temperatures and high pressure slow down the decomposition process. If wood is tightened by soil, the carbon will be buried and stored for tens or hundreds of years. Thus, the emission of carbon dioxide into the atmosphere will be prevented.

The goal of the project is long-term carbon storage, not waste disposal, which requires determination of its toxicity class and compliance with established regulations and restrictions. For this purpose, it is necessary to prove that the new technology is environmentally friendly.

Deposition is expected to take place in deep-sea ecosystems, which are extremely poor in living organisms. The only negative impact that may occur is the leaching of ester elements from the wood. However, if the concentration is low at the ecosystem scale or if the deposited material is tightened by soil, there will be no negative effect.

This approach is innovative. A methodology will need to be developed, reviewed and approved. Marine biologists need to engage to further develop the ecological component of the stage.

The depositing process can start together with the eucalyptus plantation. A system for collecting, weighing, storing and transporting residues (branches, roots, possibly leaves) from the plantation to the Atlantic coast should be developed and the cost assessed. Similarly, to produce eucalyptus products or the utilization of end-of-life wood products.

To be transported and deposited in the ocean, shredded wood must be packaged in such a way as to ensure that it does not float. The use of plastic bags will cause more ocean pollution than from natural wood. Metal nets and structures are carbon-intensive products, which can devalue the deposition process itself. The optimum would be to use fabric packs made from natural fibers and stones from the coast as weighing.

The location of the proposed deposition requires careful selection according to the following criteria:

- Be located as close as possible to the port from which it will be shipped (to reduce cost and transport emissions);
- To be outside the shelf and continental slope;
- Be located outside areas of high biodiversity or active fisheries;
- A site with rapid accumulation of soil from the mainland slope will be preferred.

Brazil’s location in relation to the Atlantic Ocean is favorable for the project. The shelf zone is narrow, with an ocean floor zone a short distance offshore, with average depths of about 3600 m [52].

Two different options on long-term deposition are considered for this stage of the project activity:

Option 1: Long-term deposit of residues (other wood fractions) in the ocean, 25% of total wood growth;

Option 2: Long-term deposit of all growing phytomass (wood + felling residues) in the ocean after it has been utilized, 95% of total wood growth.

Based on the assumptions used, the baseline information and the methodological approaches outlined above, the emissions and sequestration of CO_2 are estimated for each of the stages of the hypothetical climate project (**Table 1**).

Table 1. CO_2 emissions and removals for each stage of the hypothetical carbon project.

Stage of carbon project	CO_2 removals (−) or emissions (+), t·ha^{-1} over 7 years		
	Option 1 (baseline)	**Option 2 (carbon project)**	**Option 3 (carbon project)**
1. Plantation forestry:			
Sequestration	−403.0	−403.0	−403.0
Decomposition of phytomass	+121.0	+6.0	+6.0
Avoided emission	−282.0	−397.0	−397.0
2. Utilization of wood			
Emissions from transporting harvested wood	+1.3	+1.4 (wood processing plant in Brazil)	+1.4 (transportation to the ship); +31.4 (transportation by ships to Germany)
Emissions from the use of wood for paper production	+257.0	-	-
Disposal of stored carbon in products of long-term use	-	−282.0	−282.0
Avoided emission	-	−280.6	−249.2
3. Long-term deposit of wood residues			
Transportation before loading on a ship (100 km)	-	Deposition of residues (68.7 t) +0.5	Deposition of all phytomass (261 t) +1.9
Transport by ship to the disposal site (100 km)	-	+0.1	+0.3
Long-term ocean deposition of phytomass	-	−101.0	−403.2
Avoided emission	-	−100.4	−401.0

3.5. Economic evaluation of the climate project

Plantation forestry. To perform an economic assessment for this phase of the project activity, costs were determined based on machine hour (machine rental cost per hour or machine purchase cost), man hour (all statutory labor costs), depreciated cost of equipment (company-owned equipment), and other costs (all products used to control and maintain the plantation). A list of costs for planting operations (year 0) and plantation maintenance until harvesting age (years 1–6) was prepared, considering fixed and variable costs associated with manual and mechanical labor [53]. Planting costs including mechanical and manual labor, seedling, fertilizer and land costs were 4295.73 real/ha. The cost estimates of plantation maintenance costs from years 1 to 6 are shown in **Table 2** ([31]; authors' own calculations).

Table 2. Estimation of the cost of plantation maintenance from years 1 to 6.

Mechanical labour	**Measurement**	**Machine/ha**	**Quantity/year**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
herbicides	machine hour	1	2	11.81	11.81	11.81	11.81	11.81	11.81
mowing	machine hour	1	1	-	11.49	11.49	11.49	11.49	11.49
firefighting measures	machine hour	1	1	49.64	49.64	49.64	49.64	49.64	49.64
Interim results				61.45	72.94	72.94	72.94	72.94	72.94
Manual labour	**Measurement**	**Hour/ha**	**Quantity/year**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
land treatment against insects	man-hour	0.75	2	11.34	11.34	11.34	11.34	11.34	11.34
weeding	man-hour	4	1	75.60	75.60	75.60	-	-	-
nutrition	man-hour	2	1	45.36	45.36	45.36	-	-	-
firefighting measures	man-hour	8	1	30.24	30.24	30.24	30.24	30.24	30.24
Interim results				162.54	162.54	162.54	41.58	41.58	41.58
Other costs	**Measurement**	**Quantity/ha**	**Quantity/year**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
herbicides	kg/ha	2	2	94.00	94.00	94.00	94.00	94.00	94.00
Granulated bait	kg/ha	2	2	57.20	57.20	57.20	57.20	57.20	57.20
Nutrition (N-P-K 14-00-20)	kg/ha	167	1	213.76	213.76	213.76	-	-	-
Interim results				364.96	364.96	364.96	151.20	151.20	151.20
Annual percentage of cost land (10%)				137.00	137.00	137.00	137.00	137.00	137.00
TOTAL (real/ha/year)				725.95	737.44	737.44	402.72	402.72	402.72

Thus, the cost of purchasing the land and maintaining the plantation for 7 years until clearcutting is approximately 7704.72 Brazilian reais (BRL) per hectare, or 1482 US dollars (at the time of the calculations, the exchange rate of 1 US dollar was 5.2 Brazilian reais), which is comparable to other studies and plantation projects on eucalyptus in Brazil.

Utilization of eucalyptus in Brazil. Based on the analyzed data, we calculated the profit from the sale of eucalyptus wood products in domestic and foreign markets [54–59]. The following values were used as measures of wood growth over 7 years: 385 m^3/ha (192.5 $t \cdot ha^{-1}$) wood increment, 164.5 $m^3 \cdot ha^{-1}$ (82.25 $t \cdot ha^{-1}$) phytomass increment. In the project scenario, all wood (70% of total phytomass growth) and part of other phytomass (25% of total phytomass growth if we assume thinning and use of thin branches) is sold. At least 5% of the total wood cannot be harvested and this part remains in the ground.

Thus, values of 385 $m^3 \cdot ha^{-1}$ and 137 $m^3 \cdot ha^{-1}$ (68.7 $t \cdot ha^{-1}$) were used to calculate the profit from timber sales, respectively. The potential revenue generated from the sale of timber and other phytomass on the domestic market was 36,159.4 Brazilian reais and 157,850 Brazilian reais from the sale of timber on the European market, according to data on timber prices from the Scientific Institute of Forest Economics and Management of the University of São Paulo, Brazil (Esalq/USP) [50] and from the Food and Agriculture Organization of the United Nations [58].

Transport costs to the point of sale (as fuel cost), and a 10% surcharge for providing the service were included as additional costs [60]. The result of the calculations is summarized in **Table 3**.

Table 3. Transport costs (source: own calculations).

Indicator	Track length	Composition of cargo	Cargo volume	Cost of transport	Cost of service	Total transport costs
cost of transport to the company	100 km	wood and other phytomass	261 t (95% of total production)	2912.2 reais	291.2 reais	3203.5 reais
cost of transport to the company	100 km	other phytomass	68.7 t (25% of total production)	766.4 reais	76.6 reais	843.0 reais
cost of transport to the port	100 km	wood	192.5 t (70% of total production)	2147.8 reais	214.8 reais	2362.6 reais
cost of transport from the port of Rio de Janeiro to the port of Bremen	12,492 km	wood	192.5 t (70% of total production)	93,323.2 reais	9332.3 reais	102,655.5 reais

Costs were deducted from the revenue received in accordance with the implemented project options (domestic or foreign market). To calculate the economic feasibility of the project, NPV (Net Present Value) and IRR (Internal Rate of Return) values were calculated [61].

The evaluation showed that both options for product sales (domestic and foreign markets) were economically viable. The NPV and IRR were 4510 Brazilian reais and 27% in the first option and 13,064 Brazilian reais and 39% in the second option.

Long-term deposit of wood residues. Deposition of wood residues is possible in several options: sale of wood on the domestic market (70% of total phytomass production) and burial of phytomass residues in the ocean (25% of total phytomass production); deposition of all phytomass—wood, roots, leaves, branches (95% of total phytomass production). The calculation of the cost of transport is given in **Table 4**.

Table 4. Calculation of transport costs (source: own calculations).

Indicator	Track length	Composition of cargo	Cargo volume	Cost of transport	Cost of service	Total transport costs
cost of transport to the port	100 km	other phytomass	68.7 t (25% of total production)	766.4 reais	76.6 reais	843.0 reais
cost of transport from the port to the place of burial	100 km	other phytomass	68.7 t (25% of total production)	266.6 reais	26.7 reais	293.2 reais
cost of transport from the port to the place of burial	100 km	wood	192.5 t (70% of total production)	747.1 reais	74.7 reais	821.8 reais

Both stage options consider the assumption that the carbon deposit project will be treated as a climate project. Therefore, for carbon deposited in both projects, we expect the receipt and subsequent sale of carbon units at an average price in the offsets and carbon credit market [62,63].

For option 1, 25% of total phytomass production is buried in the ocean. When the emitted CO_2 from transport is accounted for, 100 t of CO_2 remain. The carbon units from the project may be sold at an average price of $6/t$CO_2$ (31.2 Brazilian reais); they can be sold as carbon units, which is taken as an additional income source. In year 7, the costs of road transport and maritime transport are considered. In addition, the wood (70% of the total phytomass production) is sold on the domestic market for R$32,725. The NPV and IRR of the project will be R$4306.6 and 27%, respectively.

For option 2, assumptions were made that it is possible to collect all end-of-life items. The cost of transport was R$6406.9, packaging and storage—R$12,813.8. The profit from burying all phytomass in ocean waters in this scenario depends on the sale of carbon units in the climate project. Thus, the total sequestration of CO_2 would be 401 t of CO_2, and the profit from the sale of carbon units at this volume would be R$12,511.29 at a price of $6/t$CO_2$. The project has a financial loss of 6709.5 Brazilian reais.

4. Discussion

The climate project considers social and environmental issues in the region. The situation of eucalyptus plantations in Brazil is complex [64]. In the northeastern Brazilian states of Bahia and Espirito Santo, eucalyptus monoculture plantations cover up to 70% of the area in some municipalities, replacing ecosystems of endemic Atlantic forests. Eucalyptus plantations in Brazil are considered environmentally harmful because they absorb huge amounts of water, maintain a very low diversity of flora and fauna, and require a high use of pesticides and fertilizers. Unlike natural forests, they disrupt the hydrological cycle, reduce biodiversity and do not produce food [39, 65–67]. It is necessary to prevent the creation of eucalyptus plantations on lands cleared after the felling of natural tropical forests.

As planting a new eucalyptus plantation carries high reputational risks, although it makes sense in terms of carbon sequestration, the project considered a hypothetical commercially successful existing eucalyptus plantation. However, we also considered a possible change in the regime of the existing plantation to accelerate growth and increase uptake. This reduces the need to clear-cut natural forests or transform savannahs. Additionally, the establishment and maintenance of plantations can provide job creation and employment for the local population.

The production of long-lasting eucalyptus wood products has high demand in the construction industry. Eucalyptus is one of the most demanded species for interior decoration and furniture production [68]. The use of eucalyptus wood in multi-story structures is not only economically profitable but also ensures the sustainability of the deposition effect in the wood.

Depositing unrecycled wood in the deep ocean is expected to take place in deep-ocean ecosystems that are extremely poor in living organisms, under conditions of low temperatures, limited oxygen and high pressure.

Project permanence. Each planting cycle has a rather short duration [32]. If a continuous cycle of partial harvesting and reforestation is initiated, it implies the permanence of the project in the area based on improved technologies. To ensure long-term carbon sequestration, in addition to the cycle of afforestation, it is necessary to include in the project framework the subsequent stages of wood processing and utilization.

Leaks. We expect the leakage to occur during the project, that is why it needs to be subtracted from the total amount of additional carbon sequestered. For the project to be effective, the increase in sequestration per hectare during project implementation must be sufficiently large. Leakage can be reduced by applying discount factors[2].

Considered the concept of the integrated climate project involves tracking and maximizing the reduction and avoidance of CO_2 emissions throughout the entire life cycle of products, including plantation forestry, different options for its usage, and the deposit of residues in the ocean. Application of the concept may result in almost complete emission avoidance for the proposed chain of activities with an approximate duration of 60 years or more (the wood growing cycle is 7 years, the average lifetime of a house with wood building materials is 50 years or more; regarding wood recycling cycles, the lifetime of wood can be extended up to 100 years or more). Overall, each plantation cycle can start a new chain of activities that represent a carbon reduction and mitigation cycle, lagging 7 years from the previous cycle.

Given the long-term nature of each proposed stage, business companies may be interested in considering each stage as a separate climate project. As each stage leads to emission reductions, their separate implementation will contribute to the climate effect, if carbon leakages for the planned activities are accurately analyzed and the baseline and project lines are correctly estimated and measured. This approach will allow a project developer to verify emission reductions and obtain carbon units more quickly based on offset schemes.

At the same time, implementation of the integrated project will allow transparent visibility and documentation of carbon flows, transfer of emissions/reductions from each stage/activity and tracing the leakages and double counting of emissions.

In addition to the different approaches to project implementation, there are aspects that require more research by experts. First and foremost, the proposed long-term deposit of wood residues is an innovative method of carbon burial that requires further specific environmental studies and expertise.

The proposed project idea is fundamentally different from other large-scale climate projects in the region. None of them includes the integrated whole chain from forest planting to long-term deposition. They mainly concentrated on the prevention of deforestation, improved forest management, and forest plantations—the first stage of our project idea.

For example, the main ongoing forest carbon project in Brazil is targeted at the prevention of deforestation in the Amazonian biome and getting REDD (Reducing Emissions from Deforestation and forest Degradation in developing countries) results-based payments [69,70]. As it was reported, between 2006 and 2015, Brazil achieved significant results reducing emissions from deforestation in the Amazon biome: a total of 6,125,501,727.00 tCO_2eq at 4,197,000 km^2, which corresponds to 49.29% of the national territory [70].

In Columbia, a Green Climate Fund (GCF) project includes mitigation impact from reduced deforestation, forest restoration, and preserved sinks, corresponding to 8.9 million tCO_2eq at project completion (10 years) and 46.3 million tCO_2eq cumulatively over the project lifespan (30 years) at a total investment cost of US $3.14 per tCO_2eq (US $0.93 per tCO_2eq for GCF). According to the latest NDC update, Colombia expects to reduce emissions from deforestation by 2030 to between 45.574 and 58.69 million tCO_2eq with respect to its 2020 Forest Reference Emission Levels (FREL). The project would therefore contribute between 13.8 and 17.8% of this targeted reduction [71].

The Amazon Eco Bio Business Facility in Peru provides effective climate change mitigation outcomes by investing in eco bio businesses supporting the sustainable management and conservation of Peruvian forests. The project activities will strengthen Peru’s climate change mitigation measures to prevent 8602 hectares of forest from being deforested. During the project lifetime, it will contribute to enhancing carbon stocks and avoiding the emission of 3.8 million t of CO_2 [72].

A Multi-Country Project in the Amazon basin for Brazil, Colombia, Ecuador, Guyana, Peru, and Surinam [73] promotes shifting to business models and technologies that sustainably use natural capital and forest assets (i.e., bio-businesses) to contribute to lowering the impacts of climate change, reducing GHG emissions, and increasing the region’s resilience. Activities under the program are expected to reduce to 6.2 million tCO_2eq annually (123.4 million tCO_2eq over a 20-year lifespan of investments) from forest and land use and enhance the carbon stocks of forests under improved management [73].

Another Multi-Country Project (Brazil, Cameroon, Colombia, Côte d’Ivoire, Democratic Republic of Congo, Ecuador, Gabon, Indonesia, Lao PDR, Liberia, and Zambia) [74] includes sustainable forestry with timber production as a component. The activities are supposed to: Improve the efficiency of primary wood utilization, which can serve to reduce the rate of harvesting; promote the productive use of wood waste (bioenergy, plywood, etc.); increase the forest area grown under certification standards and in compliance with national laws; select and breed fast-growing tree species that accelerate carbon sequestration and are adapted to expected climate change; promote win-win strategies that boost timber yields and promote carbon sequestration, such as protecting trees from predation and replacing low productivity forests with more vigorous stands; deploy reduced impact logging techniques, which can reduce GHG emissions by almost half while maintaining timber production; reforest degraded land with timber plantations; promote mixed species timber plantations to diversify away from climate risks; promote the use of harvested wood products in applications (furniture, buildings, etc.) that serve as durable carbon stores; as well as alternatives to materials with large carbon footprints (e.g. steel, plastics, cement); promote tenure and property rights that incentivise long-term, sustainable wood harvesting; build smallholder capacities and incentives to adopt sustainable logging practices and adapt to anticipated climate change [74]. It promotes the closed approach to the considered integrated climate project idea.

5. Conclusion

Despite the controversial attitude towards eucalyptus plantations, they can play an important role in carbon sequestration, in providing employment to local populations and in preventing additional deforestation of natural tropical forests due to the rapid production of valuable timber.

Long-term carbon storage is only possible through the production of long-life harvested wood products and the substitution of high-carbon building materials. Additional measures are needed to prevent carbon dioxide emissions after the end of the life of harvested wood products.

The proposed project will result in a total CO_2 sequestration of 403 $tCO_2 \cdot ha^{-1}$ over the life cycle of the plantation. 25% of total wood that is considered as unused industrial residues can be recycled or long-term deposited on the ocean floor. Thus, the stored carbon in the wood is 282 $tCO_2 \cdot ha^{-1}$ in baseline waste management or 397 $tCO_2 \cdot ha^{-1}$ in the project, which are transferred beyond the plantation forestry stage.

With the deduction of carbon losses during transportation, 280.6 $tCO_2 \cdot ha^{-1}$ could be buried in long life cycle products (building materials) if processed and used in Brazil and 249.2 tCO_2/ha could be deposited if wood processing would take place in Europe.

The long-term storage phase can provide an avoided emission of 100 $tCO_2 \cdot ha^{-1}$ of felling residues if they are not disposed of otherwise. If the disposal including end-of-life products as well as wood waste at all stages of processing is ensured, then the avoided emission will be 401 $tCO_2 \cdot ha^{-1}$, which is considered buried.

Thus, the full project cycle of three phases ensures that up to 95% of carbon emissions from grown wood are avoided. Even transporting wood for processing from Brazil to Europe proves cost-effective in terms of balancing leakage and long-term storage.

The economic evaluation showed that the project is profitable in the sale of wood in both domestic and foreign markets, amounting to 36,159.4 Brazilian reais and 157,850 Brazilian reais, respectively. The cost of production and sale of wood products was not estimated.

The project is also profitable if other phytomass is deposited in the ocean and sold on the domestic market over the long term. However, if all phytomass is buried in the ocean, current carbon unit prices do not cover costs and result in negative profitability.

The proposed business model differs from most existing forest-climate projects, as the main effect on the climate system is not achieved by improving the forest-growing system.

The proposed options for the long-term use of the products (more than 100 years), including for the replacement of materials with high carbon footprints (iron, concrete) are cost-effective economically and efficient in terms of carbon sequestration even if the wood is transported from Brazil to Europe.

The final component on long-term deposit of wood residues in the ocean is innovative. For its implementation, it requires recognition as a carbon-depositing project (not landfill) and the creation of a special protocol for it in the schemes of registration and release of carbon units. If this component is considered a forest-climatic component, the low price of forest carbon units may be an obstacle to its implementation. Long-term carbon storage projects have much higher unit prices, which makes the project idea cost-effective.

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Notes

[1] URL: https://kronospan.com/en_DO/company/news/view/collecting-recycling-reusing-58 (accessed on 4 November 2024).

[2] Thus, under the Verra Carbon Standard (VCS) for projects included in the Improved Forest Management (IFM) category, market leakage discount factors (LDF) apply, depending on the type of project activity.

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