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Comparative Analysis of Biomass Production, Carbon Sequestration, and Livelihood Implications in Rubber and Eucalyptus Plantations in South West Region, Cameroon

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Abstract: Plantation forestry in South West Cameroon offers both climate mitigation potential and livelihood challenges. This study comparatively assessed biomass production, carbon sequestration, and livelihood implications in a rubber (*Hevea brasiliensis*) plantation in Tiko and a Eucalyptus (*Eucalyptus globulus*) plantation in the Buea Fuelwood Reserve. Field inventory data were collected from 102 rubber trees in a 0.25 ha plot and 15 Eucalyptus trees across 0.5 ha. Aboveground and belowground biomass were estimated using allometric equations and a root-to-shoot ratio, with carbon stock and CO_2 equivalent calculated using standard conversion factors. Livelihood implications were derived from field observations and literature review. Results showed rubber had higher biomass density (141.81 t ha^{-1}) than Eucalyptus (21.56 t ha^{-1}), though Eucalyptus stored more total landscape-level carbon (5,934.05 vs. 1,301.11 t CO_2e) due to its larger area (150 ha vs. 5 ha). Livelihood implications included employment and income generation, but also land-use conflicts, reduced access to traditional resources, and food security concerns. Silvicultural practices significantly influenced biomass accumulation and wood quality. The study concludes that while both plantation systems are valuable carbon sinks, their long-term sustainability requires integrated silvicultural management, regular monitoring, equitable benefit-sharing, and socially inclusive land-use planning.

Keywords: *Aboveground Biomass; Carbon Stock; Livelihoods; Rubber; Eucalyptus; Silviculture; Cameroon*

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I. INTRODUCTION

Climate change remains one of the most pressing environmental challenges of the twenty-first century, because increasing concentrations of greenhouse gases, especially carbon dioxide (CO_2), continue to alter global temperature regimes, precipitation patterns and ecosystem stability [1]. Forest ecosystems and plantation forests contribute directly to climate regulation by absorbing atmospheric CO_2 through photosynthesis and storing carbon in stems, branches, leaves, roots, dead organic matter and soils [2, 3]. This carbon-storage function makes forest biomass assessment an essential component of sustainable forest management, climate-change mitigation, environmental reporting and land-use planning.

Plantation forests are particularly relevant in tropical regions where the demand for timber, fuelwood, poles, pulpwood, charcoal and other forest products continues to increase while natural forests remain under pressure from agricultural expansion, fuelwood harvesting, urbanization and land degradation. Properly managed plantations can reduce extraction pressure on natural forests, support rural livelihoods, rehabilitate degraded lands and contribute to carbon sequestration. However, their ecological benefits depend on species selection, site quality, stand density,

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management intensity and the duration for which carbon remains stored in living biomass or harvested wood products. Furthermore, their contribution to local livelihoods depends on how benefits are distributed, whether local communities retain access to traditional resources, and how land-use conflicts are resolved [4].

The nexus between plantation forestry and rural livelihoods has received increasing attention in recent years. In many parts of sub-Saharan Africa, large-scale land acquisitions for commercial plantations have been promoted as engines of rural development and poverty reduction [5]. Yet evidence suggests that these investments often fail to deliver promised benefits to local communities, with negative impacts on food security, land tenure, and access to forest resources [6, 7]. Women, who are often primary users of non-timber forest products, tend to be disproportionately affected by plantation expansion [8].

Eucalyptus (Eucalyptus globulus) and rubber (Hevea brasiliensis) are two important plantation systems in tropical landscapes. Eucalyptus is valued for rapid growth, short rotation, coppicing ability, fuelwood supply, pole production, pulpwood, land rehabilitation and high productivity under suitable conditions [9, 10]. Rubber plantations are primarily established for latex production, but mature rubber stands also accumulate substantial woody biomass and provide ecosystem services such as soil protection, erosion control, microclimate regulation, nutrient cycling and carbon storage [11]. In Southwest Cameroon, rubber and Eucalyptus plantations are therefore important not only for production but also for climate-smart land management.

Biomass estimation is one of the most widely used approaches for quantifying forest productivity and carbon sequestration potential. Tree biomass is generally divided into aboveground biomass, comprising stems, bark, branches and foliage, and belowground biomass, consisting mainly of roots [12, 13]. Because destructive harvesting is costly, time-consuming and often impractical, biomass is commonly estimated using allometric equations that relate tree structural variables, especially diameter at breast height (DBH), total height and wood density, to biomass [14, 15]. Biomass is then converted to carbon stock using a carbon fraction and subsequently to carbon dioxide equivalent using the molecular weight ratio of CO_2 to carbon, 44/12 or 3.667 [13].

Silviculture strongly determines the productivity, carbon storage and wood quality of plantation forests. Practices such as site preparation, spacing, weeding, fertilization, pruning, thinning, coppice regulation, pest and disease control, fire protection and rotation planning influence survival, diameter growth, height growth, stem straightness, crown development, wood density, branch size, knot formation and merchantable biomass [16, 17]. Good silvicultural management enhances stand productivity and wood quality, whereas poor management can lead to suppressed growth, excessive competition, crooked stems, large knots, reduced merchantable volume and lower carbon-storage efficiency.

Despite the ecological, economic and social importance of rubber and Eucalyptus plantations in Cameroon, localized information on biomass production, carbon stock, carbon dioxide equivalent, silvicultural determinants of wood quality, and livelihood implications remain limited. Most available forest-carbon assessments in the region have emphasized natural forest systems, leaving plantation forests comparatively under-documented. Likewise, livelihood studies have tended to focus on large-scale oil palm and rubber concessions without detailed analysis of biomass performance [18]. This study therefore combines and strengthens the available field-based materials on a Tiko rubber plantation and a Eucalyptus plantation in the Buea Fuelwood Reserve to provide a coherent comparative assessment of plantation biomass production, carbon sequestration, silvicultural implications for wood quality, and livelihood implications in the Southwest Region of Cameroon.

This study aims to conduct a comparative analysis of biomass production, carbon sequestration potential, and livelihood implications of rubber and Eucalyptus plantations in Fako Division, South-West Region of Cameroon, with emphasis on: (1) estimating aboveground and belowground biomass; (2) quantifying carbon stocks and carbon dioxide equivalent; (3) assessing the different silvicultural practices employed in both plantation systems; and (4) analyzing the implications of these plantation systems for rural livelihoods.

II. MATERIALS AND METHODS

➢ *Study Areas*

This study was conducted in the towns of Tiko and Buea (Fig. 1) in the Southwest region of Cameroon. Tiko is a coastal town located at approximately 4.075° N latitude and 9.360° E longitude. It lies in the lowlands between Douala and Limbe, near the Gulf of Guinea, and serves as an important port and agricultural center. Buea is located approximately 4.15° N latitude and 9.24° E longitude.

It is situated on the eastern and southeastern slopes of Mount Cameroon, Africa's highest volcano west of the Rift Valley. The city lies about 900 meters (3,000 feet) above sea level and serves as the administrative, educational, and commercial hub of the region. Both towns (Tiko and Buea) are situated in the Fako Division of the South-West Region of Cameroon.

The rubber component was conducted in a 5-ha rubber plantation located in Tiko. The plantation consists predominantly of Hevea brasiliensis established in 2004 at a spacing of 7 m x 3 m. Tiko lies within the humid tropical zone, where high rainfall, warm temperatures and plantation agriculture support rubber, oil palm, banana, cocoa and other crop systems.

The Eucalyptus component was conducted in the Buea Fuelwood Reserve. It was established in 1939 under British colonial administration as a protected forest area on the slopes of Mount Cameroon. The reserve contains Eucalyptus plantations managed for fuelwood and wood-resource supply.

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The area is influenced by the humid conditions and volcanic soils associated with the Mount Cameroon landscape, which can favor rapid tree growth where stand density, soil fertility and management are appropriate.

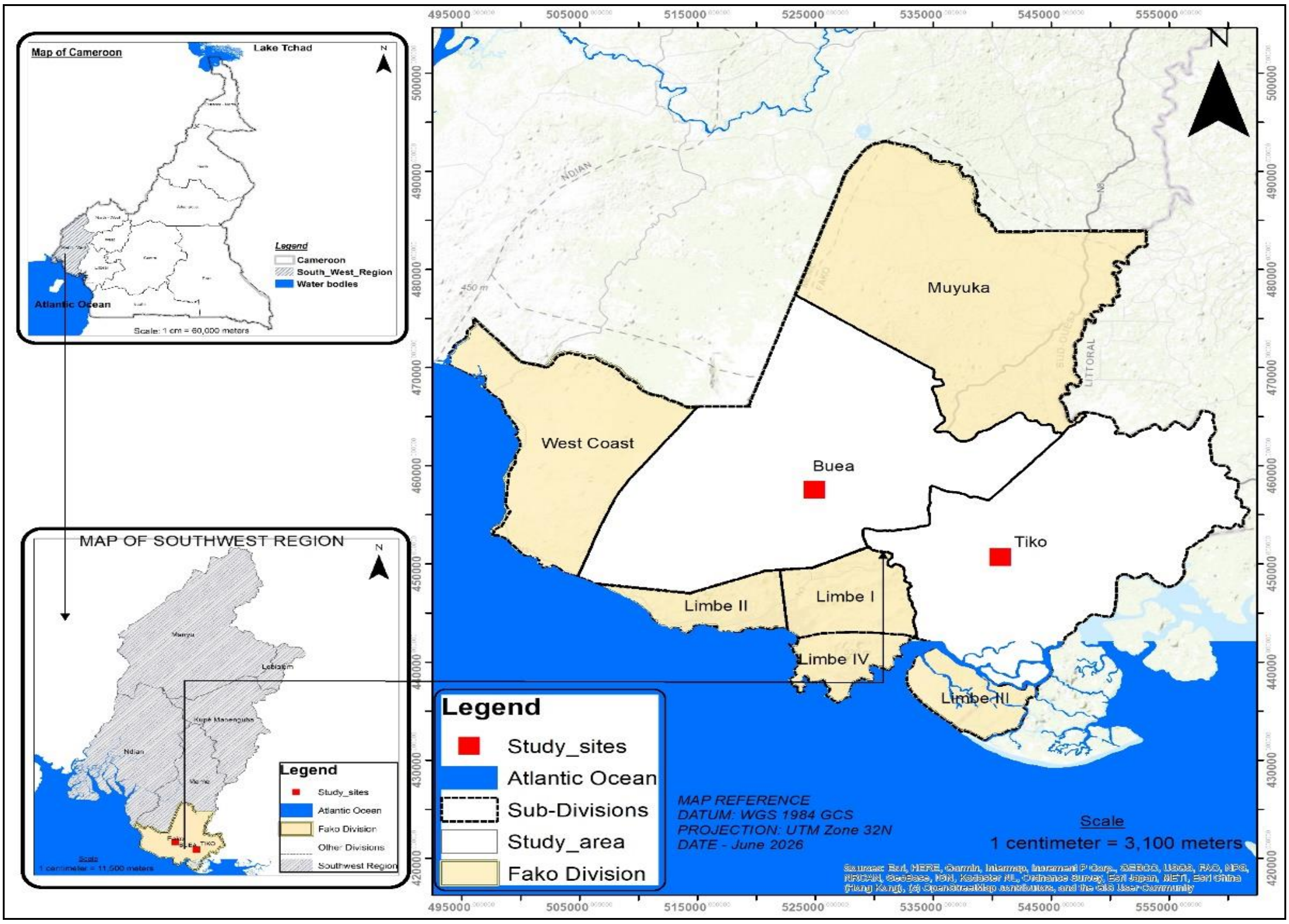

Fig 1 Map Showing the Location of Study Sites in Fako Division, Southwest Region, Cameroon

➢ *Study Design*

A field-based observational and comparative design was used. The study combined forest-inventory measurements, allometric biomass estimation, carbon conversion, qualitative assessment of silvicultural practices, and review of socioeconomic literature on plantation-related livelihoods in the region. The comparative design made it possible to evaluate both stand-level biomass density and total plantation-level carbon contribution, recognizing that these two indicators may differ when plantation areas are unequal. Livelihood implications were assessed through triangulation of field observations, documented management practices, and existing literature on plantation-society relations in Southwest Cameroon [18, 19].

➢ *Sampling and Field Measurements*

In the Tiko rubber plantation, a 50 m x 50 m sample plot, equivalent to 0.25 ha, was established within the 5-ha plantation. A total of 102 rubber trees were measured. Tree circumference was measured at approximately 1.3 m above ground and converted to DBH using $D = C/\pi$, where D is diameter and C is circumference. Tree height was recorded in metres, and a wood density value of 600 kg m^{-3} (0.60 g cm^{-3}) was used to estimate aboveground biomass, belowground biomass, total biomass, carbon and carbon dioxide equivalent.

In the Buea Fuelwood Reserve, Eucalyptus measurements were taken from two 50 m x 50 m plots, each equivalent to 0.25 ha, giving a combined sampled area of 0.5 ha. A total of 15 Eucalyptus trees were recorded across the two plots. For each tree, diameter and height was recorded. The wood density value of 600 kg m^{-3} (0.60 g cm^{-3}) was used to estimate aboveground biomass, belowground biomass, total biomass, carbon and carbon dioxide equivalent.

➢ *Biomass, Carbon and Carbon Dioxide Equivalent Estimation*

Aboveground biomass was estimated using allometric principles that relate tree diameter, height and wood density to biomass. For the rubber plantation, the Chave-type moist tropical allometric model used in the field calculation was:

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

Where AGB is aboveground biomass (kg), ρ is wood density (g cm^{-3}), D is diameter at breast height (cm) and H is total tree height (m). Belowground biomass was estimated

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from aboveground biomass using a root-to-shoot factor of 0.26 [20]:

BGB = 0.26 × AGB

Total biomass was calculated as the sum of aboveground and belowground biomass. Carbon stock was estimated by multiplying total biomass by a carbon fraction of 0.50 to maintain consistency with the supplied field calculations. It should be noted that IPCC default values commonly use 0.47 where species-specific carbon fractions are unavailable; therefore, the values reported here should be interpreted as a consistent comparative estimate based on the calculation framework used in the field materials. Carbon dioxide equivalent was estimated using the molecular conversion factor 3.667 [13]:

Total biomass = AGB + BGB

Carbon = Total biomass × 0.50

CO_2e = Carbon × 3.667

In this article, CO_2e refers to carbon dioxide equivalent stored in standing biomass at the time of assessment. It is not an annual sequestration rate unless repeated measurements over time are used to quantify net annual increment.

- *Assessment of Silvicultural Practices and Wood Quality Indicators*

Silvicultural practices were assessed through field observation and review of plantation-management information. In the rubber plantation, the observed practices included pruning, weeding and ringing, while thinning, fertilizer application, irrigation, tissue-culture propagation and genetic improvement were absent. In the Eucalyptus plantation, relevant silvicultural determinants included site preparation, spacing, weeding, pruning, thinning, coppice management, harvesting regulation, fire protection and grazing control. Wood quality was assessed indirectly through management-linked indicators such as stem straightness, branch development, knot formation, stand competition, diameter development and potential merchantable biomass. No destructive laboratory analysis of wood mechanical properties was available in the combined dataset; therefore, wood-quality interpretation was based on silvicultural indicators rather than direct laboratory testing.

- *Livelihood Implications Assessment*

Livelihood implications were assessed through three complementary approaches. First, field observations of plantation management practices provided insight into employment patterns, labor conditions, and resource-use dynamics. Second, documented plantation-management records and interviews with plantation staff during fieldwork provided information on employment numbers, wage structures, and community engagement. Third, a review of existing socioeconomic literature on plantation-community relations in Southwest Cameroon [18, 19, 21] provided context on land-use conflicts, benefit-sharing mechanisms, and impacts on subsistence livelihoods. This triangulation approach allowed identification of both positive livelihood contributions (employment, income, infrastructure) and negative impacts (land dispossession, resource access loss, conflicts).

- *Data Analysis and Harmonization*

All values were harmonized to tonnes, tonnes per hectare and total plantation estimates. Rubber values were reported for the 0.25 ha sample plot and extrapolated to the 5-ha plantation. Eucalyptus values were reported for the combined 0.5 ha sample and extrapolated to the 150 ha Buea Fuelwood Reserve. Comparative interpretation emphasized both biomass density per hectare and total landscape-level biomass and carbon storage. Livelihood implications were analyzed qualitatively using thematic categorization of positive contributions, negative impacts, and institutional factors influencing benefit distribution.

III. RESULTS

- *Sampling Characteristics*

The characteristics of the sample sites had distinct variations (Table 1) especially with respect to management objectives, tree species, tree density, and scale of operation. These differences have important implications not only for biomass production and carbon storage but also for livelihood outcomes, as larger plantations and different management objectives create different employment patterns and resource-use dynamics.

Table 1 Study-Site and Sampling Characteristics Used for the Comparative Assessment

Parameter	Tiko rubber plantation	Buea Fuelwood Eucalyptus plantation
Species/plantation type	Rubber (Hevea brasiliensis)	Eucalyptus (Eucalyptus globulus)
Location	Tiko, Southwest Cameroon	Buea Fuelwood Reserve, Southwest Cameroon
Main management purpose	Latex production with biomass and carbon-storage functions	Fuelwood, poles, wood supply and land rehabilitation
Total plantation area assessed	5 ha	150 ha
Sampled area	50 m × 50 m = 0.25 ha	Two 50 m × 50 m plots = 0.5 ha
Number of sampled trees	102	15
Planting year/age information	Established in 2004	Established in 1939
Spacing/stand structure	7 m × 3 m	Plot-based stand structure recorded from field measurements

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The Tiko rubber plantation, established primarily for latex production, represents a smaller but intensively managed system with high tree density (102 trees in 0.25 ha, approximately 408 trees ha^{-1}). The Buea Fuelwood Reserve, by contrast, is a much larger area (150 ha) managed for fuelwood and pole supply, with lower stand density (15 trees in 0.5 ha, approximately 30 trees ha^{-1}). These differences in scale, management objective, and stand density reflect different livelihood pathways: rubber plantations generate income primarily through latex sales and employment in tapping and processing, while Eucalyptus plantations generate income through fuelwood and pole sales, with carbon sequestration as a co-benefit.

➢ *Biomass Production, Carbon Stock and CO_2 Equivalent*

The Tiko rubber plantation produced the highest biomass density per hectare, and highest total biomass equivalent per hectare (Table 2). However, the Eucalyptus plantation contributed the highest total carbon dioxide equivalent because it covered a much larger plantation area (Fig. 3). Rubber biomass density was estimated at 141.81 t ha^{-1}, compared with 21.56 t ha^{-1} for the Eucalyptus sample (Fig. 2). However, because the Eucalyptus plantation covered 150 ha, its total biomass and carbon dioxide equivalent were greater at landscape scale.

Table 2 Comparative Biomass, Carbon Stock and Carbon Dioxide Equivalent Estimates

Indicator	Tiko rubber plantation	Buea Fuelwood Eucalyptus plantation
Total area assessed (ha)	5.00	150.00
Sample area (ha)	0.25	0.50
Aboveground biomass, AGB (t)	562.74	2,566.52
Belowground biomass, BGB (t)	146.31	667.30
Total biomass (t)	709.05	3,233.82
Biomass density (t ha^{-1})	141.81	21.56
Carbon stock (t C)	354.53	1,616.91
Carbon density (t C ha^{-1})	70.91	10.78
Carbon dioxide equivalent (t CO_2e)	1,301.11	5,934.05
CO_2e density (t CO_2e ha^{-1})	260.22	39.56

The higher biomass density in rubber compared with Eucalyptus reflects the combination of higher stand density (approximately 408 trees ha^{-1} versus 30 trees ha^{-1} in the sampled Eucalyptus plots) and the relatively mature age of the rubber plantation (established in 2004, approximately 18–20 years at time of assessment). The Eucalyptus plantation, despite being older (established in 1939), showed lower biomass density due to lower stand density, repeated harvesting cycles, and management focused on fuelwood production rather than maximum biomass accumulation.

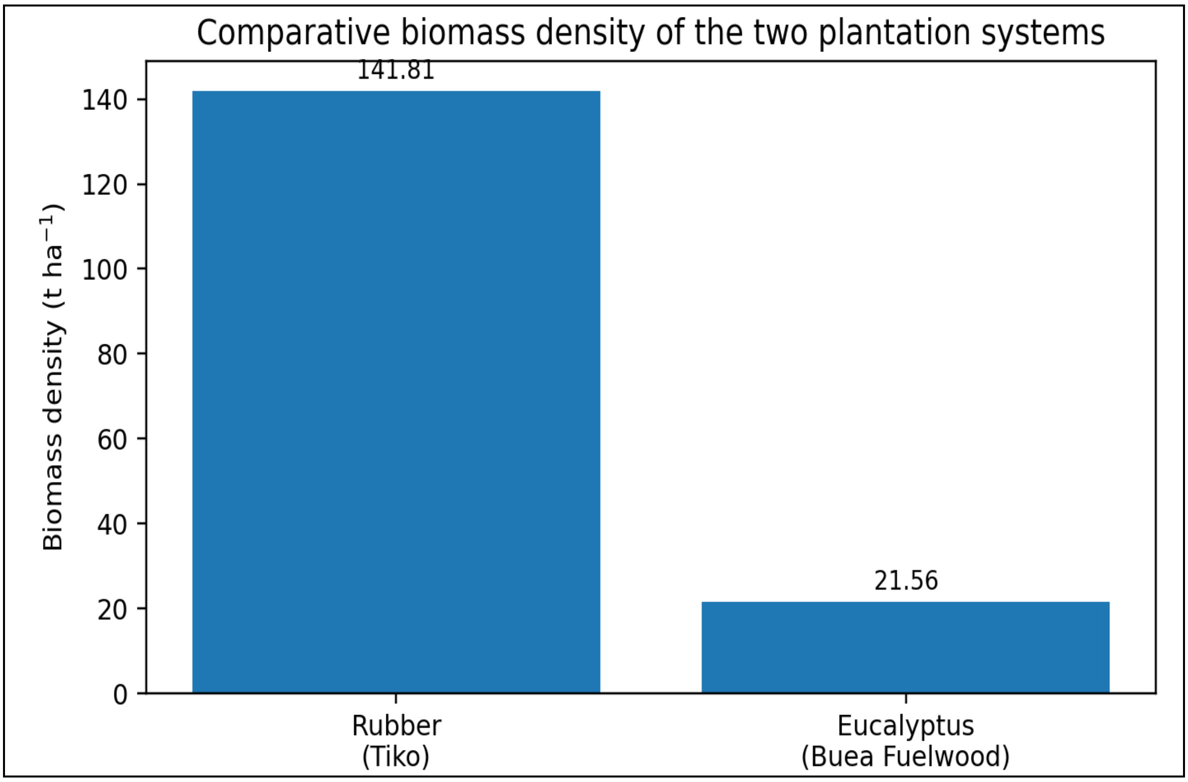

Fig 2 Stand-Level Biomass Density Comparison Between the Two Plantation Systems

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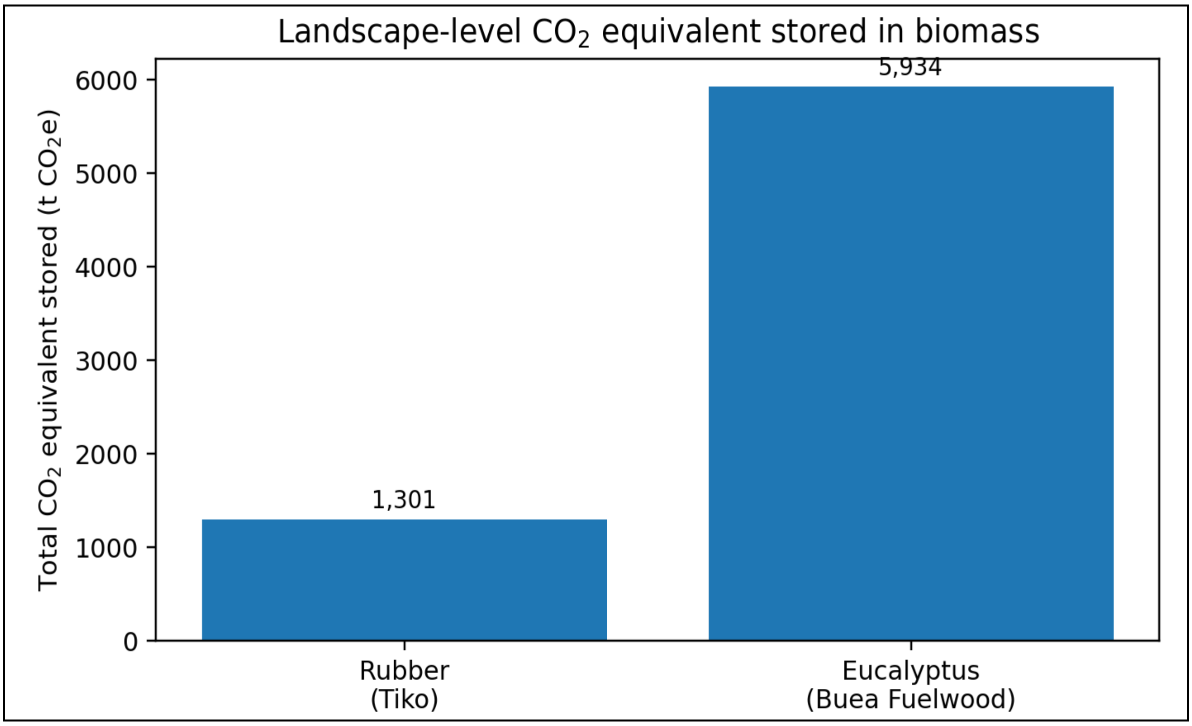

Fig 3 Total Landscape-Level Carbon Dioxide Equivalent Stored in Plantation Biomass

- *Livelihood Implications of Plantation Systems*

The comparative analysis revealed distinct livelihood implications for the two plantation systems, summarized in Table 3. These implications encompass both positive contributions and negative impacts on local communities.

Table 3 Livelihood Implications of Rubber and Eucalyptus Plantations in Southwest Cameroon

Dimension	Tiko Rubber Plantation	Buea Fuelwood Eucalyptus Plantation
Employment	Direct employment in tapping, processing, and management; historically significant employer in the region [18]	Fuelwood harvesting, pole cutting, and plantation management; provides seasonal and informal employment
Income generation	Regular income from latex sales; 5-ha scale supports fewer workers than larger rubber concessions	Income from fuelwood and pole sales; often informal and seasonal
Land-use change	Conversion of land to monoculture rubber; potential displacement of subsistence agriculture [19]	Plantation established on former forest reserve land; primarily on Mount Cameroon slopes with limited agricultural value
Resource access	Limited access to non-timber forest products within plantation; potential impact on women's livelihoods [8]	Fuelwood access regulated; limited understory resources for gathering
Land tenure/conflict	Potential land-use conflicts where plantations expand on customary land [21]	Less conflict due to established reserve status; but local communities may have customary claims
Food security	Potential negative impacts if prime agricultural land converted to plantation	Limited impact as area is on steep slopes less suited to farming
Gender dimensions	Women may be excluded from tapping employment; loss of NTFP gathering areas [8]	Women's fuelwood collection may be affected by plantation management
Social conflict	Tensions between plantation management and local communities over land rights [18]	Lower conflict intensity but competition for fuelwood resources may exist
Carbon benefits	Carbon sequestration contributes to climate mitigation; potential for carbon credit schemes	Carbon sequestration; potential for carbon offset payments if monetized
Infrastructure	Road access, potential for community development projects in larger concessions	Minimal infrastructure development

The livelihood implications of these plantation systems are shaped by several key factors. First, scale matters: larger plantations (such as the 150-ha Eucalyptus plantation) can provide greater aggregate employment and biomass-related benefits, but also create more extensive land-use change. Second, management purpose influences livelihood outcomes: latex production requires regular tapping labor and creates consistent income streams, while fuelwood

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production generates more seasonal and informal employment. Third, land-use history affects conflict levels: plantations established on already-designated forest reserves may face less community opposition than those established through conversion of customary lands [18].

The carbon sequestration values reported in Table 2 also have livelihood implications through potential carbon credit mechanisms. If monetized, the stored carbon could generate additional income for plantation managers and potentially for local communities through benefit-sharing arrangements. The rubber plantation's 1,301.11 t CO_2e and the Eucalyptus plantation's 5,934.05 t CO_2e represent substantial carbon assets that could be valued under voluntary carbon markets or national climate finance mechanisms. However, realizing these benefits requires appropriate institutional frameworks and equitable benefit-sharing arrangements to ensure that local communities share in the proceeds.

➢ *Silvicultural Practices and Implications for Wood Quality and Livelihoods*

The silvicultural practices varied between the Eucalyptus and rubber plantations (Table 4), with the rubber plantation undergoing better management. These practices influence not only biomass production and wood quality but also livelihood outcomes through their effects on employment intensity, product quality, and long-term plantation productivity.

Table 4 Silvicultural Practices and Implications for Wood Quality and Livelihoods

Practice	Tiko rubber plantation	Buea Fuelwood Eucalyptus plantation	Implication for biomass and wood quality	Livelihood implication
Spacing/stand density	7 m × 3 m spacing; moderate competition and canopy development	Stand structure captured in plot data; spacing and density regulation relevant	Controls resource competition, diameter growth, crown expansion, branch size and stand-level biomass	Affects labor requirements for planting, thinning, and harvesting; influences timing of income generation
Weeding	Observed and used to reduce understory competition	Important for early establishment and stand productivity	Improves access to light, nutrients and moisture; supports height and diameter growth	Creates employment opportunities for weeders; may affect NTFP availability
Pruning	Observed up to about 2 m during early stages	Important for stem form and clear wood	Reduces branch knots, improves stem straightness and increases potential merchantable quality	Requires skilled labor; improves wood value and potential income
Thinning	Absent	Recognized as important but must be well timed and controlled	Reduces competition and improves diameter growth; absence may cause suppression, while excessive thinning may cause large branches	Creates employment through timber/fuelwood extraction; influences timing of revenue generation
Fertilizer/nutrient management	Absent; productivity depends mainly on natural fertility and rainfall	Important where repeated biomass removal depletes soil nutrients	Maintains long-term soil productivity, biomass accumulation and wood quality	Increases production costs; may reduce long-term productivity if absent
Irrigation	Absent; rainfall supports growth	Not emphasized; natural moisture conditions dominate	Relevant in dry periods but less critical where rainfall is adequate	No significant employment implication
Fire and grazing protection	Not specifically documented	Critical for Eucalyptus stand survival and wood quality	Reduces stem damage, mortality, regeneration failure and carbon losses	Protects livelihood assets; fire prevention creates community engagement opportunities
Coppice/rotation management	Not applicable to latex-oriented management	Highly relevant for Eucalyptus fuelwood systems	Controls shoot density, stem straightness, product size and sustained biomass supply	Creates regular employment cycles; ensures sustained fuelwood supply

The absence of thinning and fertilizer application in the rubber plantation has both ecological and livelihood implications. While maintaining higher stand density supports greater per-hectare biomass, it may reduce individual tree diameter growth and potentially lower latex yields over time. Without fertilizer inputs, long-term soil fertility may decline, affecting both biomass accumulation and latex production, which is the primary source of income for plantation workers. The presence of pruning creates employment for plantation workers, as does weeding.

However, the more regular and formalized employment in rubber tapping provides more stable income compared with the seasonal and often informal work associated with fuelwood harvesting in Eucalyptus plantations.

IV. DISCUSSION

➢ *Comparative Biomass Production*

The comparison reveals two important but different carbon-accounting outcomes. First, the rubber plantation showed substantially higher biomass density and CO_2 stock per hectare than the sampled Eucalyptus plantation. This suggests strong stand-level biomass accumulation in the mature rubber plantation under the humid conditions of Tiko. The 7 m × 3 m spacing may have provided sufficient growing space for individual tree diameter development while maintaining enough stand density for total biomass accumulation. The age of the plantation, established in 2004, also suggests that trees had passed the juvenile stage and had accumulated considerable woody biomass. These findings are consistent with other studies showing that mature rubber plantations can achieve high biomass densities in tropical environments [11, 22].

However, the Eucalyptus plantation contributed higher total biomass and CO_2e at landscape scale because the assessed plantation area was much larger. This distinction is important for interpreting plantation carbon performance. A plantation may show lower biomass density per hectare but still store more total carbon if it occupies a large area. Conversely, a smaller plantation may show high stand-level carbon density but lower total carbon contribution because of limited area. Therefore, plantation carbon assessment should report both density-based values and total area-based estimates. For livelihood and policy purposes, this suggests that carbon-related benefits (such as potential payments for ecosystem services) should consider both per-hectare performance and total plantation area, which may influence which plantations are prioritized for carbon crediting.

➢ *Influence of Tree Diameter and Height on Biomass*

The rubber-tree examples clearly show that biomass increases strongly with DBH and height. This is consistent with allometric theory because stem diameter captures much of the variation in tree volume and woody tissue mass. The use of D^2 in the allometric model means that modest increases in diameter can produce disproportionately large increases in biomass. Height and wood density further refine the estimates by accounting for vertical growth and the mass of wood per unit volume [14]. The Eucalyptus data similarly show higher biomass values among larger and taller trees, reflecting the same structural relationship between tree size and biomass accumulation.

For livelihoods, the relationship between tree size and biomass has practical implications. Larger trees represent greater stored carbon value and greater potential product value. Plantation management practices that promote diameter growth (such as appropriate thinning and spacing) can therefore enhance both carbon storage and economic returns. However, there may be trade-offs between maximizing biomass and maximizing other livelihood benefits (such as latex production in rubber, where tapping requires trees to reach a minimum diameter).

➢ *Carbon Stock and Carbon Dioxide Equivalent*

The higher carbon stock and carbon dioxide equivalent per hectare for rubber than for Eucalyptus could be directly related to the higher biomass production for rubber. Because carbon stock was calculated as a fixed fraction of biomass, the ranking of carbon stocks follows the ranking of biomass values. Rubber recorded 354.53 t C over 5 ha, while the Eucalyptus plantation recorded 1,616.91 t C over 150 ha. The corresponding CO_2e values were 1,301.11 t CO_2e and 5,934.05 t CO_2e respectively. These estimates demonstrate that both plantation systems perform important climate-regulating functions by storing atmospheric carbon in standing biomass. However, they should be interpreted as stocks at the time of inventory rather than annual sequestration rates. Estimating annual sequestration would require repeated measurements over time or reliable growth-increment data.

The values also highlight the relevance of biomass monitoring for carbon-accounting initiatives, afforestation planning and climate-smart forestry. If plantation biomass is harvested for short-lived fuelwood and rapidly combusted, much of the stored carbon may return to the atmosphere quickly. If harvested biomass is converted into durable products, carbon may remain stored for longer periods. Carbon permanence therefore depends not only on biological growth but also on harvesting regime, product use, rotation length and post-harvest management.

For livelihoods, the carbon sequestration values suggest potential for carbon finance to supplement income from conventional plantation products. The rubber plantation's 1,301.11 t CO_2e and the Eucalyptus plantation's 5,934.05 t CO_2e could potentially generate revenue through voluntary carbon markets or national REDD+ mechanisms. However, realizing this potential requires addressing governance challenges, ensuring equitable benefit-sharing, and establishing reliable monitoring, reporting, and verification (MRV) systems [23, 24]. Without such systems, carbon benefits may accrue primarily to plantation owners rather than local communities.

➢ *Livelihood Implications of Plantation Systems*

The livelihood implications of rubber and Eucalyptus plantations in Southwest Cameroon are complex and context-dependent. On the positive side, both plantation types provide employment and income. Rubber plantations, particularly those managed by large companies like the Cameroon Development Corporation (CDC), have historically been significant employers in the region [18]. The 5-ha rubber plantation studied, while smaller than the CDC's major concessions, still generates employment through latex tapping, weeding, pruning, and plantation management. Eucalyptus plantations provide employment through fuelwood harvesting, pole cutting, and plantation maintenance, though this employment tends to be more seasonal and informal.

However, the evidence suggests that the positive livelihood contributions of plantations may be unevenly distributed. Women, who are often primary users of non-timber forest products (NTFPs) and subsistence farmers, may be disproportionately affected by plantation expansion through loss of access to traditional resource areas [8]. Studies of large-scale land acquisitions in Cameroon have documented tensions between corporate plantation interests and local communities, with communities often feeling excluded from decision-making processes [19, 21]. The expansion of rubber plantations, in particular, has been associated with land-use conflicts, as prime agricultural land is converted to monoculture plantations.

For the Eucalyptus plantation in the Buea Fuelwood Reserve, the situation is different. The reserve status of the area means that land-use conversion did not involve displacing subsistence agriculture. However, local communities who traditionally gathered fuelwood and other forest products from the area may face restrictions on access. The management of the reserve for fuelwood production creates a regulated supply that may benefit some community members (those with access to harvesting opportunities) while potentially disadvantageing others (those who relied on free access to the area).

The carbon sequestration potential of both plantation types also has livelihood implications through potential carbon credit mechanisms. If monetized, the stored carbon could generate additional income for plantation managers and potentially for local communities through benefit-sharing arrangements. However, realizing these benefits requires appropriate institutional frameworks and equitable benefit-sharing arrangements to ensure that local communities share in the proceeds [23, 24]. The scale of carbon stored, 1,301.11 t CO_2e for the 5-ha rubber plantation and 5,934.05 t CO_2e for the 150-ha Eucalyptus plantation, suggests that carbon markets could provide meaningful supplementary income, particularly if carbon prices increase over time.

➢ *Silvicultural Determinants of Biomass and Wood Quality*

Silvicultural practices emerged as central determinants of both biomass production and potential wood quality. In rubber, pruning and weeding are beneficial because they reduce unwanted branches and minimize competition from understory vegetation. Pruning during early growth improves stem form and reduces branch-related defects. Weeding supports access to light, nutrients and soil moisture, especially during establishment. Ringing was also observed as a plantation-maintenance practice, although its specific effect depends on purpose, timing and implementation.

The absence of thinning in the rubber plantation may have mixed implications. On one hand, maintaining high stand density can increase stand-level biomass. On the other hand, excessive competition can suppress diameter growth, produce slender stems and reduce potential merchantable wood quality. The absence of fertilizer application and irrigation means that productivity depends mainly on natural soil fertility, rainfall and residue-mediated nutrient cycling. In a humid tropical environment, natural rainfall may be adequate, but nutrient extraction through latex production, litter removal or eventual wood harvesting can reduce long-term site fertility if not managed.

In Eucalyptus plantations, spacing, thinning, pruning, coppice regulation and fire protection are especially important. Narrow spacing may increase early biomass per hectare but can reduce individual tree diameter. Wider spacing can improve diameter growth but may encourage larger branches and knots if pruning is delayed. Proper thinning redistributes growing space to selected trees, improves diameter growth and can enhance wood quality, but overly heavy thinning may reduce stand volume and promote excessive branch development [16, 25]. Coppice management is particularly relevant where Eucalyptus is harvested for fuelwood because uncontrolled coppice shoots can create overcrowded stools, irregular stems and reduced product quality.

For livelihoods, the silvicultural practices matter because they influence employment patterns and product quality. Intensive silviculture (such as pruning, thinning, and weeding) requires more labor, potentially generating more employment opportunities. However, this labor intensity also increases plantation management costs, which may affect the economic viability of plantations and thus the sustainability of employment. Silvicultural practices that improve wood quality can increase product value and thus potentially support higher wages or more stable employment.

➢ *Ecological, Economic, and Social Management Implications*

The findings support the view that plantation forests can complement natural forests in climate-change mitigation and wood supply, but they should not be treated as ecological substitutes for natural forests. Monoculture plantations generally have lower biodiversity and structural complexity than natural forests. Eucalyptus plantations may also raise concerns relating to soil nutrient depletion, water use, fire risk and understory simplification where management is poor. Rubber plantations may support some ecosystem services, but their carbon and biodiversity values depend on age, canopy structure, understory management, chemical inputs and landscape context.

For Southwest Cameroon, the practical implication is that plantation forestry should be integrated into broader land-use planning that considers both ecological sustainability and livelihood outcomes. Rubber plantations can be recognized as latex-production systems with significant biomass and carbon-storage functions, while Eucalyptus plantations can support fuelwood and pole supply that may reduce pressure on natural forests if managed sustainably. Regular biomass monitoring, appropriate silvicultural prescriptions, mixed-species buffers, soil fertility management and fire protection would improve both production and environmental outcomes.

The livelihood implications suggest that plantation development should be accompanied by measures to protect community interests. This includes securing land tenure

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rights for local communities, ensuring equitable benefit-sharing from plantation products and potential carbon credits, maintaining access to subsistence resources (particularly for women), and involving communities in decision-making about plantation management. The tension between plantation expansion and community livelihoods observed in other parts of Cameroon [18, 19] suggests that proactive measures are needed to prevent conflicts.

V. LIMITATIONS OF THE STUDY

This study has several limitations that should be acknowledged. First, wood quality was interpreted from silvicultural indicators rather than direct laboratory measurements such as wood density variation, fiber properties, mechanical strength or moisture content. Second, the reported CO_2e values are standing biomass carbon equivalents, not annual sequestration rates. Third, soil carbon, litter carbon and deadwood carbon were not fully quantified in the comparative calculations, meaning total ecosystem carbon stocks are likely underestimated. Fourth, extrapolation assumes that sampled plots represent the wider plantation areas; this assumption should be tested with larger stratified sampling across stand age, density, slope and management conditions.

For the livelihood analysis, limitations include the reliance on secondary literature for some socioeconomic data and the absence of primary household surveys. Future research should incorporate direct household surveys, focus group discussions, and participatory methods to better understand how plantation systems affect different social groups, particularly women and marginalized communities. Additionally, the study did not quantify the economic value of carbon sequestration or analyze the potential for carbon credit schemes in the study area. Future research should address these gaps through detailed cost-benefit analysis and institutional assessment.

VI. CONCLUSION

This comparative study demonstrates that plantation ecosystems in Southwest Cameroon have significant potential for biomass production, carbon storage, atmospheric carbon dioxide removal, wood-resource development, and livelihood support when they are properly established and managed. The Tiko rubber plantation and the Eucalyptus plantation in the Buea Fuelwood Reserve both accumulated measurable aboveground and belowground biomass, confirming the usefulness of plantation forests as productive land-use systems and functional carbon sinks.

The Tiko rubber plantation recorded a higher biomass density per hectare, indicating strong stand-level biomass accumulation under humid tropical conditions. This finding shows that mature rubber plantations should not be viewed only as latex-production systems but also as important reservoirs of woody biomass and stored carbon. The rubber plantation also provides more regular and formal employment through latex tapping and plantation management, contributing to stable income generation for workers.

In contrast, the Eucalyptus plantation showed lower biomass density in the sampled plots but greater total landscape-level carbon contribution because of its larger plantation area. This confirms that carbon sequestration potential is determined not only by tree growth per hectare but also by plantation extent, stand density, rotation length and management intensity. The Eucalyptus plantation provides more seasonal and informal employment through fuelwood harvesting and pole cutting, with different livelihood implications.

Silvicultural practices were central to the interpretation of biomass and potential wood quality. Spacing, weeding, pruning, thinning, nutrient management, fire protection, grazing control and coppice regulation influence tree growth, stem form, branch development, knot formation, wood density and merchantable biomass. These practices also shape employment patterns and livelihood outcomes through their effects on labor demand and product value.

The livelihood analysis revealed both positive and negative implications. Plantations contribute to employment and income generation but can also create land-use conflicts, reduce access to traditional forest resources, and negatively affect food security and women's livelihoods. The study therefore concludes that rubber and Eucalyptus plantations can contribute meaningfully to climate-change mitigation, wood supply, and rural livelihoods in Southwest Cameroon, but their long-term ecological, economic, and social value requires evidence-based silviculture, regular biomass monitoring, equitable benefit-sharing mechanisms, protection of community resource rights, and integration into climate-smart and socially inclusive forestry policy.

RECOMMENDATIONS

➢ *Based on the Findings of this Study, the Following Recommendations are Proposed:*

- Expand biomass monitoring: Establish additional sample plots across age classes, slope positions and management regimes to improve the precision of biomass and carbon estimates. Regular monitoring of DBH, height, survival, stand density and biomass increment should be implemented to distinguish carbon stocks from annual sequestration rates.
- Strengthen silvicultural management: Introduce evidence-based thinning and pruning schedules that balance biomass production with stem quality and merchantable wood value. In rubber plantations, consider periodic thinning to improve diameter growth and latex yield. In Eucalyptus plantations, implement controlled thinning and coppice management to sustain productivity and wood quality.
- Improve soil fertility management: Implement practices such as organic residue retention, mulching, targeted fertilization where necessary, and reduced nutrient losses after harvesting to maintain long-term site productivity.

- Enhance fire and grazing management: Strengthen firebreaks, grazing control and community awareness around Eucalyptus plantations to reduce carbon losses and stem damage. Fire protection is particularly critical in Eucalyptus plantations on the Mount Cameroon slopes.
- Develop equitable benefit-sharing mechanisms: Establish clear frameworks for sharing benefits from plantation products and potential carbon credits with local communities. This includes transparent revenue-sharing arrangements, community development agreements, and mechanisms for community participation in plantation decision-making.
- Protect community resource rights: Secure land tenure rights for local communities and maintain access to subsistence resources, particularly for women who depend on non-timber forest products and subsistence agriculture. This includes establishing buffer zones and maintaining corridors for traditional resource use.
- Promote gender-inclusive approaches: Ensure that women benefit equitably from plantation employment and that their traditional resource use rights are protected. This may include targeted employment opportunities, women's participation in plantation management committees, and gender-sensitive impact assessments.
- Consider mixed-species and agroforestry systems: Plant mixed-species buffers and incorporate native vegetation conservation to improve biodiversity, soil stability and ecological resilience around plantation blocks. Agroforestry approaches that integrate plantation trees with food crops could reduce negative impacts on food security.
- Investigate carbon finance potential: Conduct detailed feasibility studies on carbon credit schemes for plantation systems in Southwest Cameroon. This includes assessing carbon market access, monitoring costs, and institutional requirements for successful carbon finance.
- Use complementary technologies: Employ complementary technologies such as GPS mapping, UAV imagery, LiDAR and remote sensing to improve plantation inventory, monitoring and carbon accounting. These technologies can reduce monitoring costs and improve accuracy.
- Conduct participatory livelihood assessments: Undertake detailed household surveys, focus group discussions, and participatory rural appraisals to understand how plantation systems affect different social groups and to identify locally appropriate livelihood enhancement strategies.
- Strengthen policy integration: Integrate plantation carbon assessment into national climate-change policy, REDD+ frameworks, and land-use planning. This includes developing national guidelines for plantation carbon accounting and livelihood impact assessment.

REFERENCES

[1]. Stips A., Macias D., Coughlan C., Garcia-Gorriz E., Duarte CM., On the causal structure between CO2 and global temperature, Sci Rep, 2016;6:21691. doi:10.1038/srep21691
[2]. Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. Science, 320(5882), 1444–1449. https://doi.org/10.1126/science.1155121.
[3]. Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. Science, 333(6045), 988–993. https://doi.org/10.1126/science.1201609
[4]. Adams, W. M., & Mortimore, M. J. (1997). Agricultural intensification and flexibility in the Nigerian Sahel. The Geographical Journal, 163, 150–160.
[5]. Borras, S. M., Jr., & Franco, J. C. (2012). Global land grabbing and trajectories of agrarian change: A preliminary analysis. Journal of Agrarian Change, 12(1), 34–59. https:
[6]. //doi.org/10.1111/j.1471-0366.2011.00339.x
[7]. Cotula, L., Vermeulen, S., Leonard, R., & Keeley, J. (2009). Land grab or development opportunity? Agricultural investment and international land deals in Africa. London: International Institute for Environment and Development (IIED).
[8]. Hall, R. (2011). Land grabbing in Southern Africa. The Journal of Peasant Studies, 38(2), 193–214.
[9]. Fonjong, L. (2017). Left out but not backing down: Exploring women's voices against large-scale agro-plantations in Cameroon. Development in Practice, 27(8), 1114–1125. https://doi.org/10.1080/09614524.2017.1360258
[10]. Evans, J., & Turnbull, J. W. (2004). Plantation forestry in the tropics: The role, silviculture, and use of planted forests for industrial, social, environmental, and agroforestry purposes (3rd ed.). Oxford University Press.
[11]. Ferraz Filho, A. C., Scolforo, J. R. S., & Mola-Yudego, B. (2014). The coppice-with-standards silvicultural system as applied to Eucalyptus plantations: A review. Journal of Forestry Research, 25(2), 237–248. https://doi.org/10.1007/s11676-014-0455-0
[12]. Brown, S. (1997). Estimating biomass and biomass change of tropical forests: A primer (FAO Forestry Paper 134). Food and Agriculture Organization of the United Nations.
[13]. Intergovernmental Panel on Climate Change. (2006). 2006 IPCC guidelines for national greenhouse gas inventories: Volume 4 - Agriculture, forestry and other land use. IPCC.
[14]. Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. C., Duque, A., Eid, T., Fearnside, P. M., Goodman, R. C., Henry, M., Martínez-Yrizar, A., Mugasha, W. A., Muller-Landau, H. C., Mencuccini, M., Nelson, B. W., Ngomanda, A., Nogueira, E. M., Ortiz-Malavassi, E., ... Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of

tropical trees. Global Change Biology, 20(10), 3177-3190. https://doi.org/10.1111/gcb.12629
[15]. Parresol, B. R. (1999). Assessing tree and stand biomass: A review with examples and critical comparisons. Forest Science, 45(4), 573–593.
[16]. Schönau, A. P. G., & Coetzee, J. (1989). Initial spacing, stand density and thinning in eucalypt plantations. Forest Ecology and Management, 29(4), 245–266. https: //doi.org/10.1016/ 0378-1127(89)90100-2
[17]. Smith, D. M., Larson, B. C., Kelty, M. J., & Ashton, P. M. S. (1997). The practice of silviculture: Applied forest ecology (9th ed.). John Wiley & Sons.
[18]. Nkwain, N. L., Nkenne, J. M., Bomono, H. Y., & Simun, R. F. (2024). Large-scale agro-industries and host community land restitution demands: understanding the land-use conflicts between the CDC and Fako elites in the south west region, Cameroon. Sociology International Journal, 8(4), 183–188.
[19]. IIED & CED. (2019). Apes, crops and communities: Land concessions and conservation in Cameroon (IIED Briefing). International Institute for Environment and Development. https: //iied.org/17710iied
[20]. Kuyah, S., Dietz, J., Muthuri, C., Jamnadass, R., Mwangi, P., Coe, R., & Neufeldt, H. (2012). Allometric equations for estimating biomass in agricultural landscapes: II. Belowground biomass. Agriculture, Ecosystems and Environment, 158, 225–234. https: //doi.org/10.1016/j.agee.2012.05.010
[21]. Sunjo, E., & Page, B. (2022). Land restitution and conflict in Cameroon: The case of the Bakweri. African Affairs, 121(485), 623–648. https://doi.org/10.1093/afraf/adac034
[22]. Rafdinal, R., Pitopang, R., Linda, R., Raynaldo, A., & Subrata, E. (2021). Comparative study of aboveground biomass and carbon storage between Tembawang and conventional rubber agroforestry in West Kalimantan, Indonesia. Acta Agriculturae Slovenica, 117(1), 1–7.
[23]. WWF. (2024). How to unlock carbon and biodiversity finance for community forest managers. WWF.
[24]. Tennigkeit, T., Solymosi, K., Seebauer, M., & Lager, B. (2011). Carbon intensification and poverty reduction in Kenya: Lessons from the Kenya agricultural carbon project. Land Portal.
[25]. Resquin, F., Navarro-Cerrillo, R. M., Carrasco-Letelier, L., & Carrasco, P. (2024). Impact of thinning on the yield and quality of Eucalyptus wood. Forests, 15(5), 810. https://doi.org/10.3390/f15050810