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Optimal Allocation and Sustainable Management of Ghana's Forest

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Background and Problem

Forests in Africa (23% land area) are pivotal for biodiversity conservation, carbon storage, and socio-cultural continuity. Ghana's forestry sector contributes employment, export earnings, soil protection, climate regulation, and watershed integrity.

However, deforestation rates (≈3.5% average annual loss 2001–2015) have escalated with >18,000 ha lost in 2022, intensifying pressure on the High Forest Zone. Continued decline threatens ecosystem service flows, carbon sequestration, and economic opportunities. These trends erode adaptive capacity and heighten vulnerability to climate and market shocks.

Objectives

- Quantify temporal and spatial patterns of forest cover dynamics
- Identify drivers of tree cover area loss.
- Examine Relationship between tree cover loss and carbon emissions.
- Model an optimal allocation of Ghana's forest.

Data Sources

- Global Forest Watch (Hansen et al. 2013): annual tree cover loss/gain, driver classification, emissions.

Table 1. Model Parameters and Sources

Parameter	Value / Unit	Source
Discount rate (r)	3%/annum	Hiltunen et. al., (2021)
Carbon price (p_c)	\$20/Mg CO_2e	OECD (2023)
Agric. revenue/hectare (p_a)	\$400/ha/year	Taylor, Beillard and Galloway (2025)
Reforestation cost (c_r)	\$2,000/ha	EcoEcon and Republic of Ghana (2014)
Amenity value (A)	\$164/ha/year	Obeng et al. (2020)
Forest growth rate (r)	5% (logistic growth)	Kusi (2025)
Carbon sequestration rate (s)	1.5 Mg CO_2e/ha/year	Nero et al. (2024)

Optimal Allocation Modelling

$$NB_t = A \cdot X_t + R_t + C_t \tag{1}$$

$$R_t = \begin{cases} p_a \cdot Y_t, & Y_t > 0 \\ -c_r \cdot |Y_t|, & Y_t < 0 \end{cases} \tag{2}$$

$$C_t = \begin{cases} -e \cdot p_c \cdot Y_t, & Y_t > 0 \\ s \cdot p_c \cdot |Y_t|, & Y_t < 0 \end{cases} \tag{3}$$

$$PV = \sum_{t=0}^{T-1} \frac{NB_t}{(1+d)^t} + \frac{NB_\infty}{(1+d)^T} \tag{4}$$

$$NB_\infty = A \cdot X_T + F(X_T) \cdot s \cdot p_c \tag{5}$$

$$F(X_t) = r \cdot X_t \cdot \left(1 - \frac{X_t}{K}\right) \tag{6}$$

$$X_{t+1} = X_t + F(X_t) - Y_t, \tag{7}$$

$$0 \le X_t \le K, \quad X_0 = X_{2000} \tag{8}$$

$$X_{MSY} = \frac{K}{2}, \quad F(X_{MSY}) = \frac{rK}{4} \tag{9}$$

(4) is the objective funtion, (6)-(9) are the contraints

- NB_t = net societal benefit at time t
- R_t = net economic return (deforestation/reforestation)
- C_t = net carbon-related cost/benefit
- X_t = forest stock at time t
- Y_t = net change in forest area (positive = loss, negative = gain)
- NB_∞ = terminal net benefit
- PV = present value of net benefits
- K = environmental carrying capacity
- $F(X_t)$ = forest growth at time t
- X_{MSY} = forest stock at maximum sustainable yield

All other parameters are as defined in Table 1.

Tree Cover Loss and Carbon Emissions

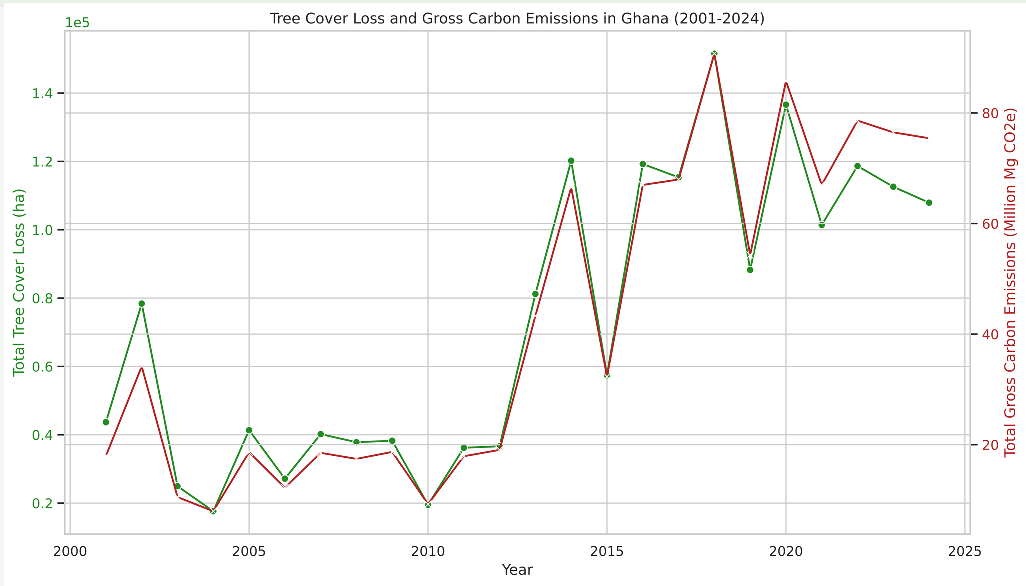


Figure 1. Tree Cover Loss and Carbon Emissions

- Accelerating annual loss post-2012 with intermittent spikes.
- Strong positive relationship between loss and emissions (near-linear).

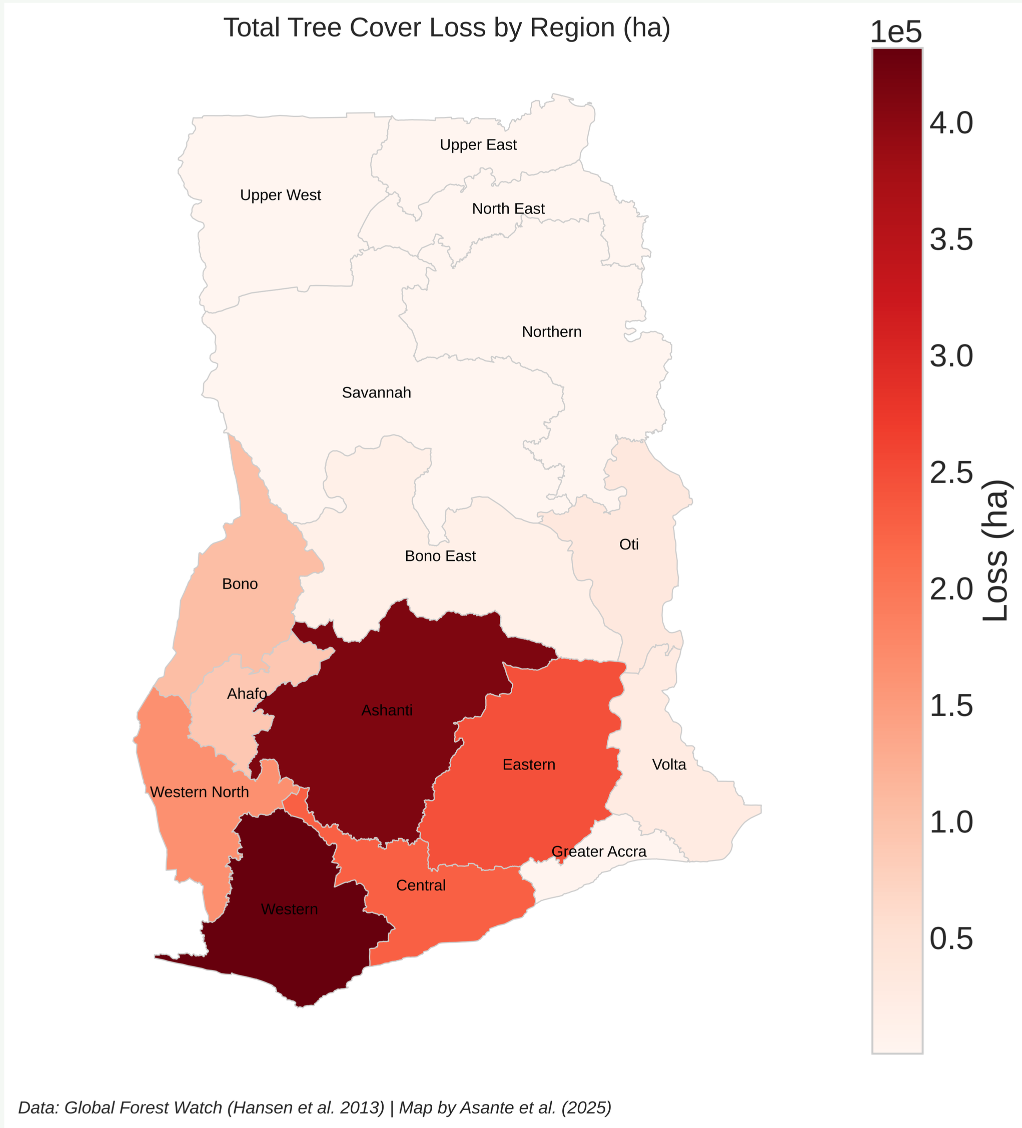


Figure 2. Tree Cover Loss by Regions

- Top cumulative loss regions (2001–2024): Ashanti ≈ Western > Eastern > Central > Western North > Bono > Ahafo > Bono East > Oti > Volta.

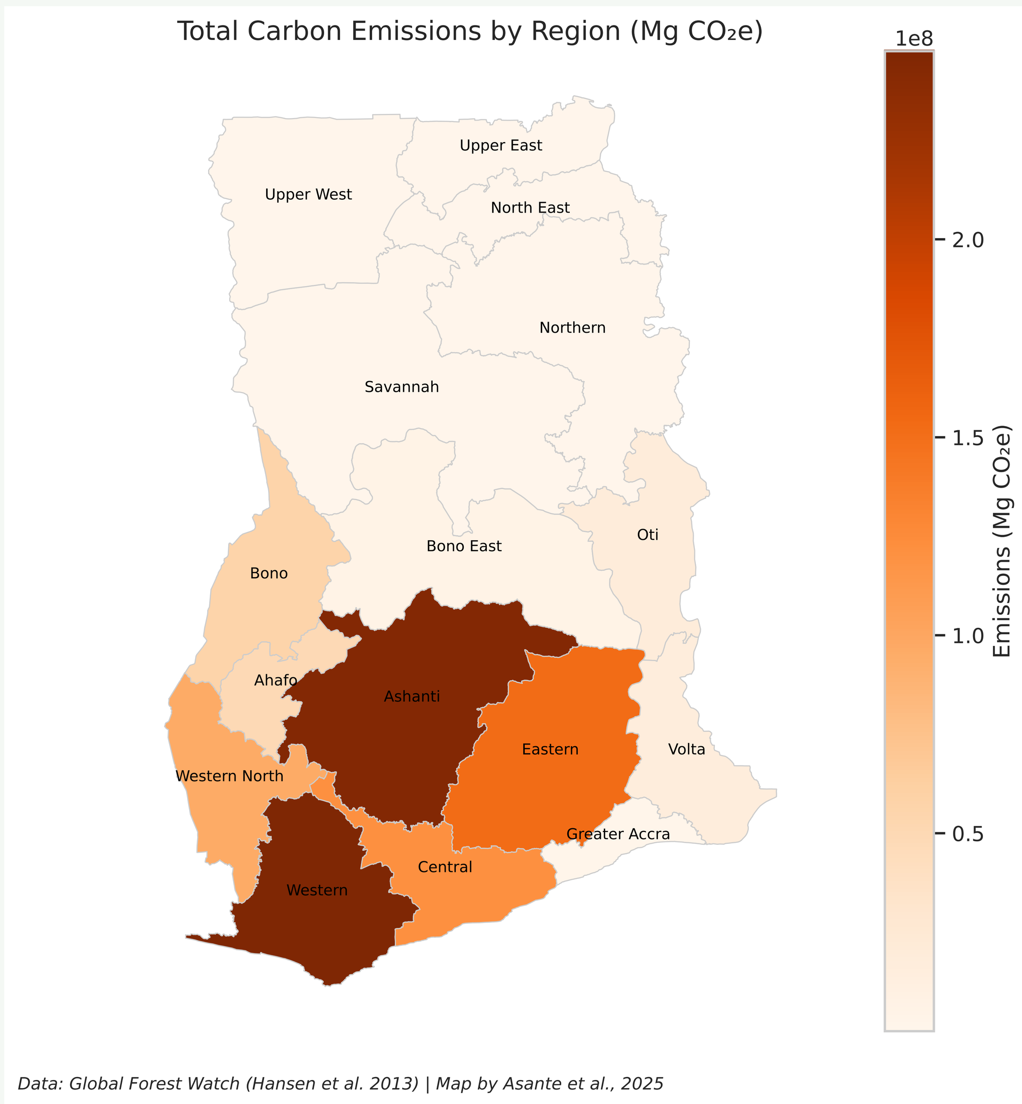
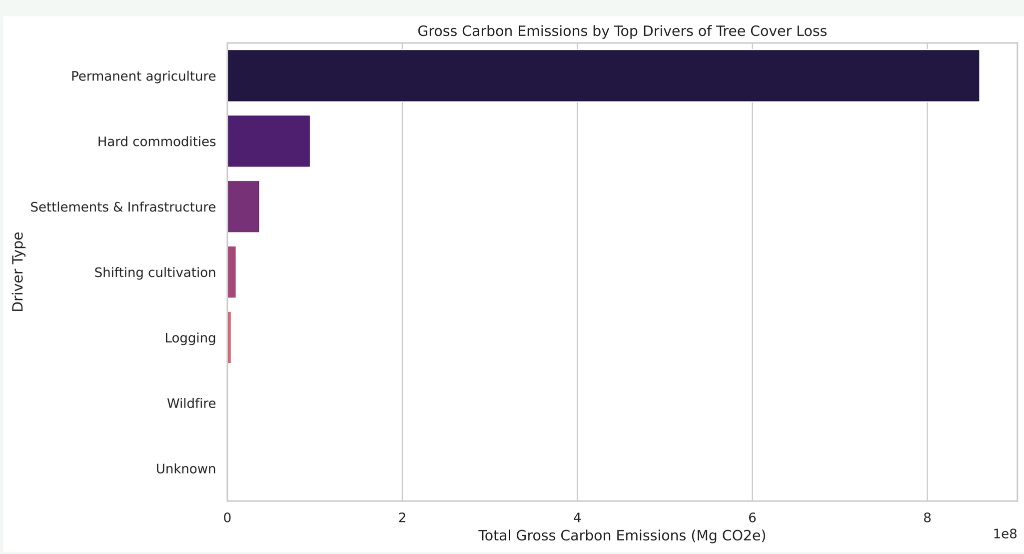
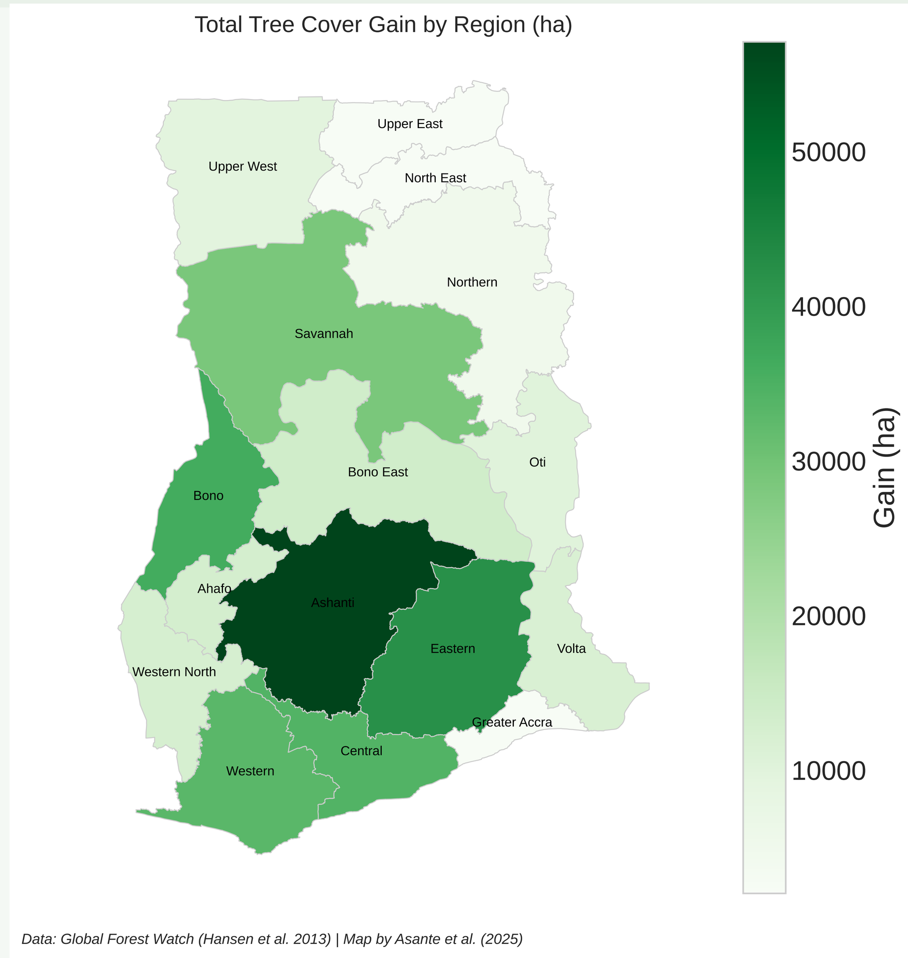


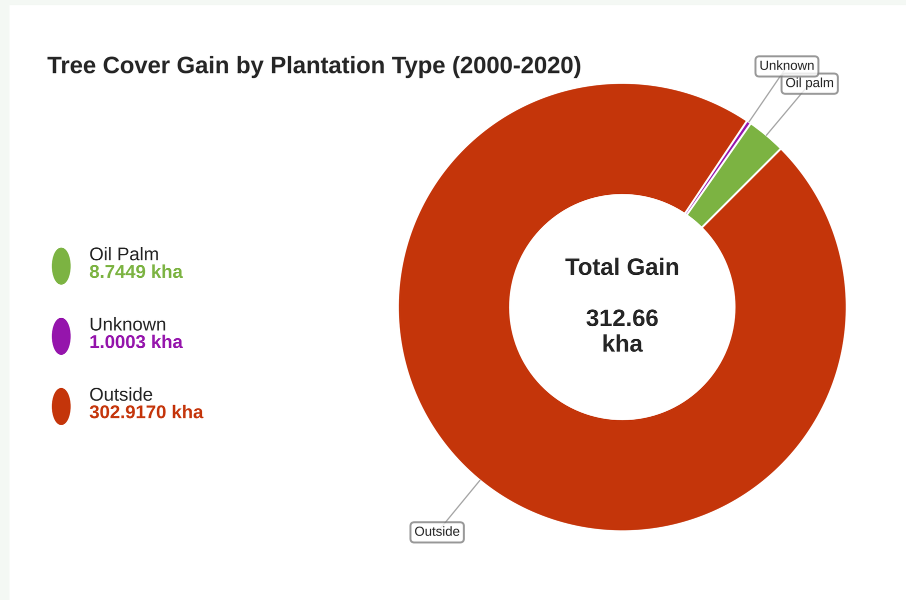
Figure 3. Carbon Emissions by Regions



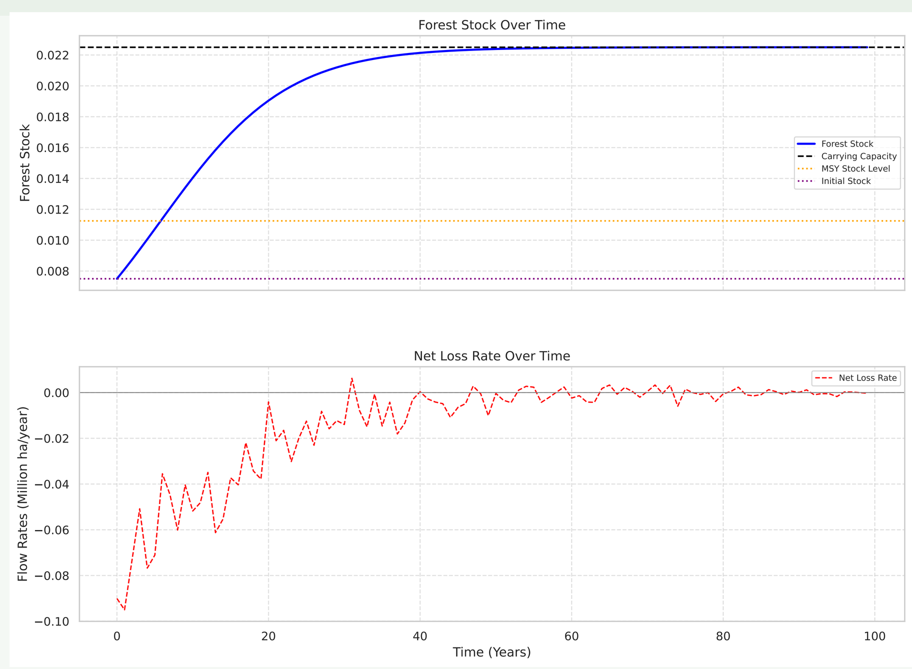
Permanent agriculture dominates (>85% of total loss & emissions), followed by hard commodities & settlements infrastructure. Logging, shifting cultivation, wildfire remain small but locally impactful.

Tree Cover Gain





Optimization Results



Policy Implications

1. Focus on agricultural intensification in cocoa-growing regions (Ashanti and Western) to improve yields on existing farmlands.
2. Implement stricter rules and rehabilitation mandates for high-emission activities.
3. Direct greater portion of conservation funding to Ashanti, Western, Eastern, and Central regions for forest protection, alternative livelihoods, and reforestation.
4. Promote natural regeneration over plantations by incentivising ecosystem service payments to encourage natural regrowth.

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