CODEX PLANETARIUS

A Supply Shed Analysis of Cocoa Cooperatives in Côte d'Ivoire

Epoch

About *Codex Planetarius*

Codex Planetarius is a proposed system of minimum environmental performance standards for producing globally traded food. It is modeled on the *Codex Alimentarius*, a set of minimum mandatory health and safety standards for globally traded food. The goal of *Codex Planetarius* is to measure and manage the key environmental impacts of food production, acknowledging that while some resources may be renewable, they may be consumed at a faster rate than the planet can renew them.

The global production of food has had the largest impact of any human activity on the planet. Continuing increases in population and per capita income, accompanied by dietary shifts, are putting even more pressure on the planet and its ability to regenerate renewable resources. We need to reduce food production's key impacts.

The impacts of food production are not spread evenly among producers. Data across commodities suggest that the bottom 10-20% of producers account for 60-80% of the impacts associated globally with producing any commodity, even though they produce only 5-10% of the product. We need to focus on the bottom.

Once approved, *Codex Planetarius* will provide governments and trade authorities with a baseline for environmental performance in the global trade of food and soft commodities. It won't replace what governments already do. Rather, it will help build consensus about key impacts, how to measure them, and what minimum acceptable performance should be for global trade. We need a common escalator of continuous improvement.

These papers are part of a multiyear proof of concept to answer questions and explore issues, launch an informed discussion, and help create a pathway to assess the overall viability of *Codex Planetarius*. We believe *Codex Planetarius* would improve food production and reduce its environmental impact on the planet.

This proof-of-concept research and analysis is funded by the Gordon and Betty Moore Foundation and led by World Wildlife Fund in collaboration with a number of global organizations and experts.

For more information, visit www.codexplanetarius.org

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Executive Summary

Côte d'Ivoire supplies approximately 40 – 45% of global cocoa demand and remains one of the fastest-growing economies in West Africa. As the country launches implementation of its National Development Plan (NDP 2026–2030), aimed at consolidating strong, sustainable and inclusive growth while strengthening competitiveness and improving living conditions, balancing economic expansion with environmental stewardship becomes increasingly central to long-term resilience. Historical cocoa expansion has contributed substantially to forest loss, land-use change (LUC) emissions and biodiversity decline. As international frameworks such as EU Deforestation Regulation (EUDR), Task Force on Nature-Related Financial Disclosures (TNFD), and Corporate Sustainability Reporting Directive (CSRD) raise expectations for supply chain transparency and environmental performance, there is an urgent need for spatially explicit intelligence to support both accountability and transformation.

This study applies a geospatial supply shed methodology to 3,711 cocoa cooperatives to assess environmental exposure within the first phase of the supply chain, across four dimensions: deforestation, LUC emissions, biodiversity and water stress. The analysis aligns with the principles of the *Codex Planetarius* initiative, which seeks to reduce the environmental footprint of globally traded commodities by identifying and improving the least efficient or highest-impact production systems using harmonized metrics.

The results reveal two distinct patterns of environmental risk:

- **Deforestation and LUC emissions are concentrated.**
  The top 20% of cooperatives account for 64.2% of exposure to non-compliant deforestation and 53.3% of exposure to LUC emissions. This indicates that a relatively small proportion of actors are associated with a disproportionate share of carbon-related land-use pressures, creating opportunities for targeted engagement consistent with *Codex* principles.
- **Biodiversity loss and water stress are systemic.**
  Biodiversity exposure (Gini = 0.002) and water stress (Gini = 0.031) are broadly distributed across cooperatives, reflecting structural landscape conditions shaped by historical conversion and climatic stress. These risks cannot be addressed through isolated action and instead require landscape-scale governance, restoration, and resilience-building strategies.

Cocoa production remains geographically concentrated in the southern regions, closely linked to export infrastructure. With planned economic expansion under the NDP 2026–2030, including continued structural reforms and investment promotion, ensuring that productivity gains occur within ecological limits will be essential to maintaining long-term competitiveness and environmental integrity.

Together, the findings of this analysis support a dual strategy under *Codex Planetarius*: targeted improvement among high-impact actors to rapidly reduce deforestation and LUC emissions, combined with systemic landscape-level interventions to restore biodiversity and strengthen climate resilience across the sector.

Introduction: Geospatial Intelligence for Sustainable Supply Chains

Côte d'Ivoire's economy heavily relies on cocoa, as the world's leading exporter, supplying 40-45% of global demand.[1] The commodity generates 10-15% of the country's GDP and accounts for 35% of its export earnings.[2] Future economic growth is also tied to the sector, with efforts to increase in-country processing rather than exporting lower-value raw goods.

However, the cocoa sector is the primary driver of deforestation and subsequent Land Use Change (LUC) emissions in Côte d'Ivoire, resulting in a 62% loss of natural forest between 1960 and 2010. Furthermore, the sector is vulnerable to climate change, forecasted by the World Bank in 2018 (World Bank, 2018) and evidenced by the 2025 drought that reduced output by approximately 40% due to rising temperatures.[3,4] This presents a major challenge in balancing economic growth with environmental sustainability.

The international context adds complexity, as commodity importers face rising pressure to demonstrate strong environmental stewardship, with scrutiny focused on deforestation, LUC emissions, biodiversity loss, and water scarcity. Consequently, effective global trade and meeting regulatory and societal expectations are increasingly dependent on comprehensive supply chain transparency, necessitating precise geographic identification of growing and processing areas.

This increased demand for robust supply chain intelligence is driven by stricter voluntary and mandatory regulations, including the European Union Deforestation Regulation (EUDR), the Taskforce for Nature-related Financial Disclosures (TNFD), and the Corporate Sustainability Reporting Directive (CSRD).

This report extends an established analytical approach (Blue, 2025), previously applied to the palm oil sector in Indonesia, to focus on the cocoa commodity within Côte d'Ivoire. We leverage geospatial data, an essential resource for measuring proxy environmental indicators, to investigate the correlation between the primary drivers of environmental impacts within the supply chain. The findings are analyzed within the context of global standards for environmental performance, such as the proposed *Codex Planetarius* (Clay, 2016), a system aimed at safeguarding renewable natural resources by targeting the least efficient producers and fostering international consensus on standardized metrics.

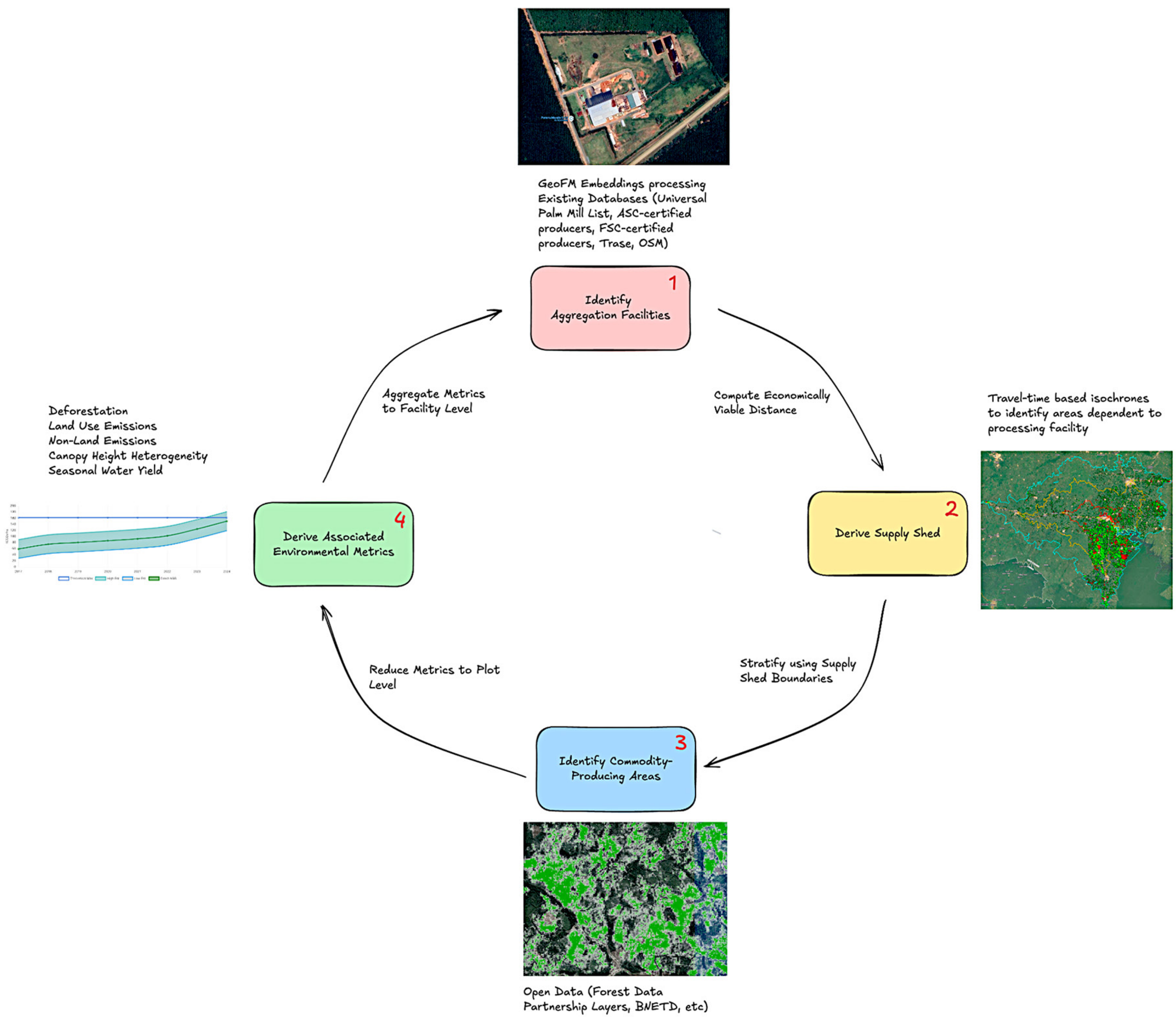
The following document details the methodology and analyses the findings within the framework of *Codex Planetarius* principles.

Analytical Framework: Geospatial Supply Shed Approach

This study applies a geospatial supply shed framework to quantify environmental exposure within the first mile of the cocoa supply chain – the cultivation, aggregation and pre-export processing stages. The objective is to spatially link cooperative aggregation facilities to their potential sourcing landscapes and assess environmental conditions within those areas.

The approach follows four sequential steps shown in Figure 1 (below).

Figure 1. The data production lifecycle for the proposed agricultural first mile database



A detailed technical description of the methodology is provided in *Codex Planetarius* Study: Palm in Paradise (Blue, 2025). The summary below highlights the core analytical logic as applied to cocoa in Côte d'Ivoire.

Cooperative Aggregation Locations

Cooperative facility data were sourced from the Trase Côte d'Ivoire cocoa cooperative database (Trase, 2025), which builds upon prior work examining cooperative–buyer relationships (Guye, 2024a, 2024b; Renier et al., 2023). The dataset contains 3,711 cooperative aggregation facilities with associated metadata and geographic coordinates.

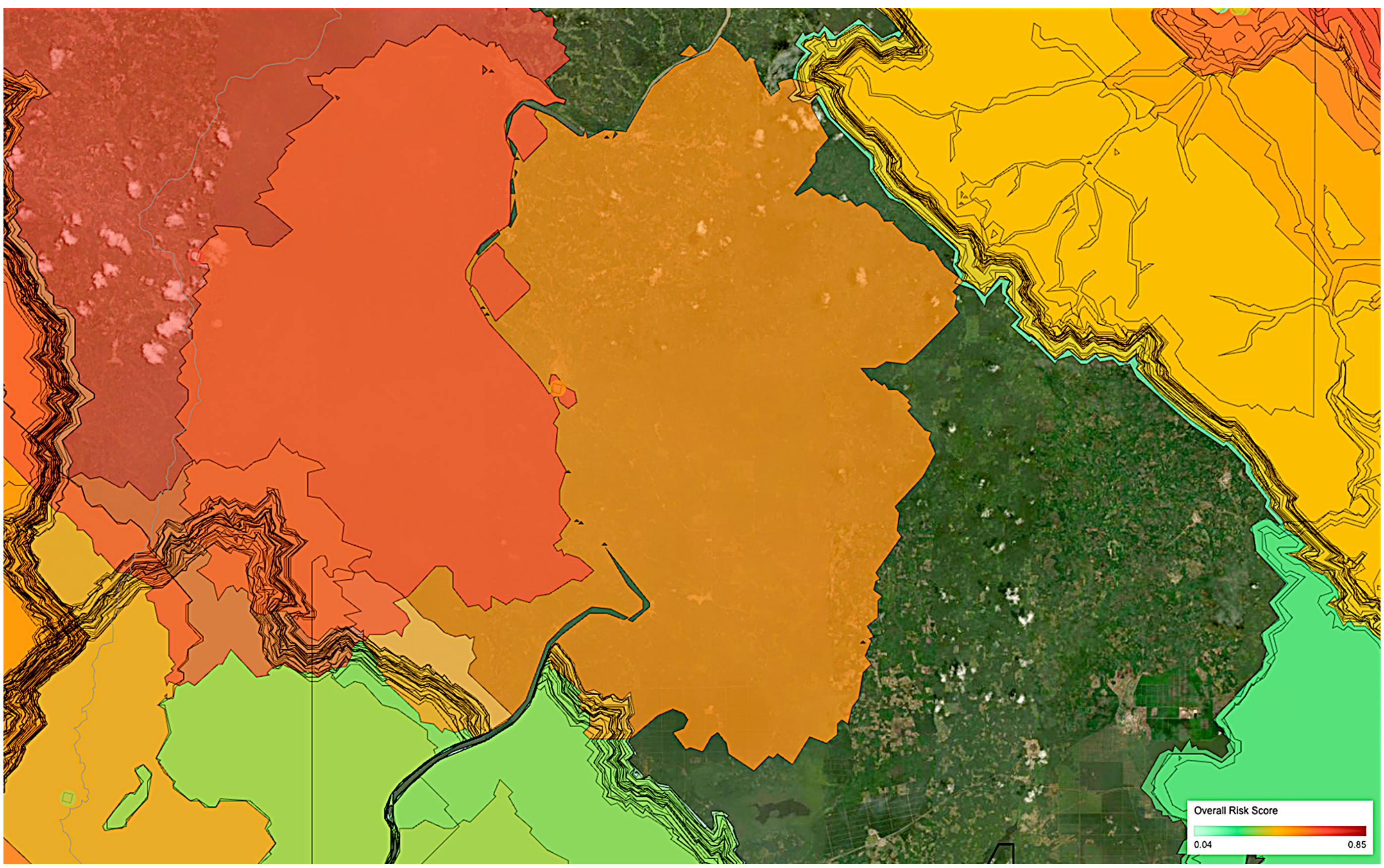
Facility locations are assumed spatially valid through 2025. Environmental exposure is assessed for 2017–2025, with non-compliant deforestation restricted to forest loss occurring after the EUDR cut-off date of 31 December 2020.

Probabilistic Supply Shed Derivation

Supply sheds are derived using probabilistic travel isochrones rather than fixed-radius buffers. These incorporate road accessibility, terrain constraints, land cover, hydrological barriers and commodity-specific transport limitations. The resulting polygons represent modelled sourcing territories reflecting plausible cooperative influence.

Supply sheds are not mutually exclusive and may overlap spatially. Consequently, environmental metrics represent exposure within modelled sourcing areas rather than uniquely attributed sourcing territories. An example of multiple overlapping supply sheds is shown in Figure 2 (below). Note the presence of a river preventing a fully connected supply shed in the center of the image.

Figure 2. An example of multiple cocoa cooperative overlapping supply sheds



Identification of Cocoa Production Areas

Within each supply shed, cocoa production areas are identified using probabilistic commodity maps produced by the Forest Data Partnership and Google (Forest Data Partnership and Google, 2025).[5] Where required, proprietary classification approaches may supplement existing datasets using agro-ecological zones[6] and embeddings datasets, such as AlphaEarth Embeddings.[7] Commodity probability rasters are discretized into vector polygons using consistent parameters (Table 1).

Table 1: Vectorization parameters

Parameter	Value	Description
Scale	• 10m for FDP commodity maps and embeddings-derived commodity maps • 30m for other datasets	Determines the scale at which vectorization takes place
Probability Threshold	0.8 for cocoa	Determines which pixels become vectors (> 80% probability)
Minimum Mapping Unit	0.5 hectare for cocoa	Filters out noise/small patches

Environmental Exposure Metrics

Environmental exposure is calculated within each cooperative's supply shed using geospatial proxy indicators aligned with supply chain risk domains (Table 2). These indicators provide spatially explicit proxies linking landscape conditions to cooperative-level environmental exposure.

Table 2: Proxy indicators by risk domain

Risk Category	Proxy Indicator	Rationale
Climate & Emissions	Post-2020 deforestation area and above-ground biomass loss	Captures land-use change emissions and regulatory non-compliance exposure
Biodiversity & Ecosystem Health	Canopy height heterogeneity (Rao's Q)	Low heterogeneity indicates simplified, monoculture-dominated landscapes
Water & Hydrology	Meteorological water stress index	Reflects climate-driven water constraints affecting yield stability
Land & Soil Health	Soil erosion and sediment yield	Measures degradation of productive land capital

Composite Risk Score (Comparative Screening Tool)

To enable prioritization across cooperatives, a composite risk score is calculated as the equal-weighted mean of percentile-ranked components:

$$Risk = 1/5 \times [PR(Total\ Emissions] + (1 - PR(Diversity)) + PR(Water\ Stress) + PR(Noncompliance) + PR(Commodity/Supply\ shed)\ ]$$

Where:

- **PR** denotes percentile rank (0–1 scale) across all facilities
- Higher values indicate higher relative exposure

Percentile ranking normalizes heterogeneous indicators onto a common scale, limiting sensitivity to extreme outliers and ensuring comparability across risk domains.

The composite score is designed as a relative prioritization and screening tool rather than a measure of absolute ecological harm. It enables identification of cooperatives with comparatively higher combined exposure across multiple environmental dimensions.

Landscape Structure of Cocoa Production

Having established the analytical framework, we next examine the structural characteristics of cocoa production landscapes in Côte d'Ivoire. Understanding the spatial configuration of cooperative facilities, supply sheds and cocoa cover is essential for interpreting subsequent environmental exposure patterns.

Geographic Distribution of Cooperatives

Cocoa cooperatives are concentrated in the southern half of Côte d'Ivoire, consistent with agro-climatic suitability for cocoa cultivation (Abu et al., 2021). Facility validation indicates high positional confidence (>96%) (Figure 3, below), supporting the reliability of the spatial analysis.

Aggregation density is particularly pronounced in the Bas-Sassandra district (Figure 4, page 8), which contains approximately 26% of all mapped cooperatives. This concentration reflects proximity to the Port of San Pedro, the primary export corridor for cocoa.[8] The planned expansion[9] of port and associated infrastructure may increase throughput capacity and reinforce production intensity within this region.

Figure 3. The geographical spread of cocoa cooperatives along with their assigned facility confidence score (3711 distinct facilities total, high - 3613, medium - 91, low - 7).

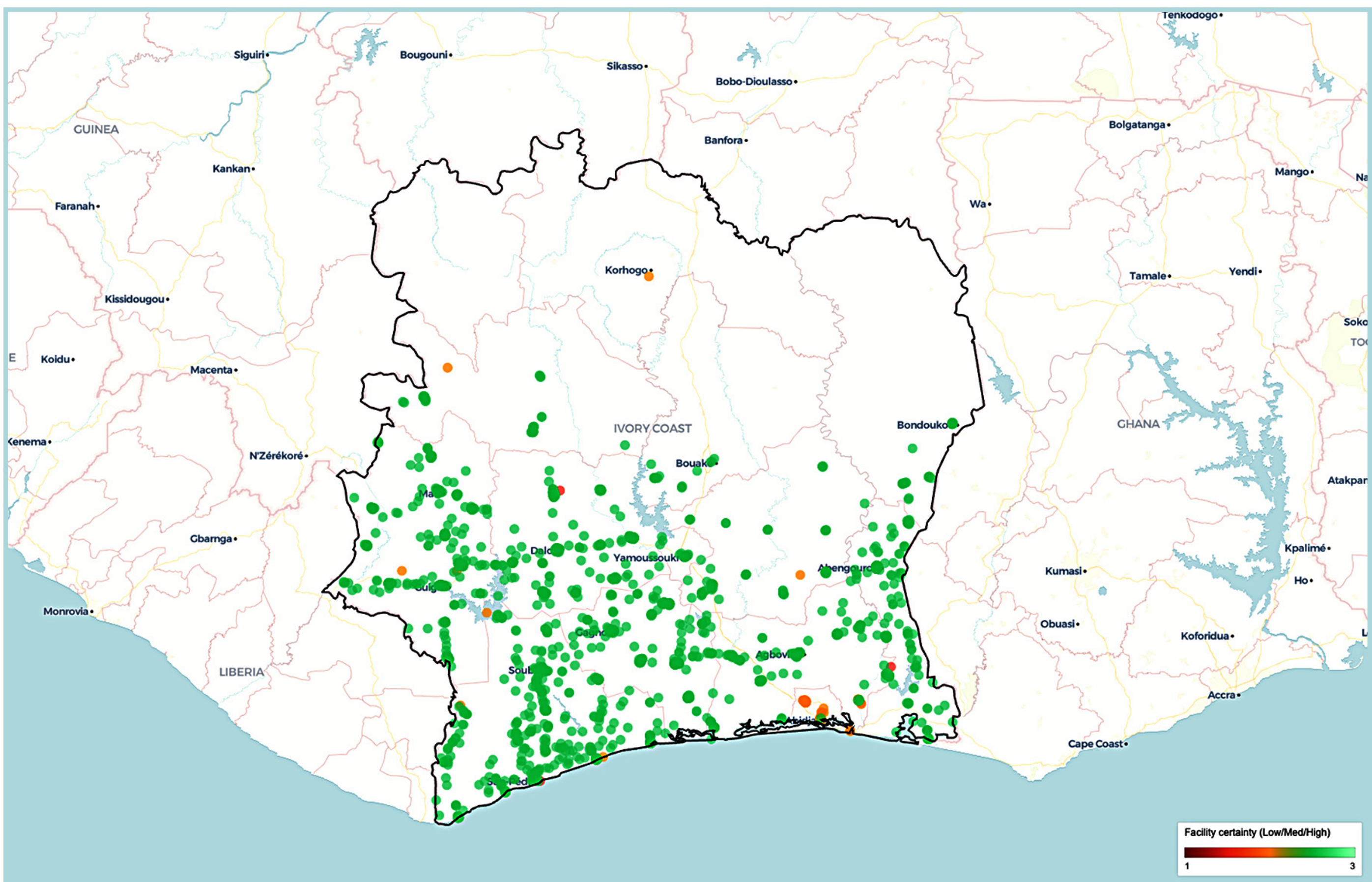
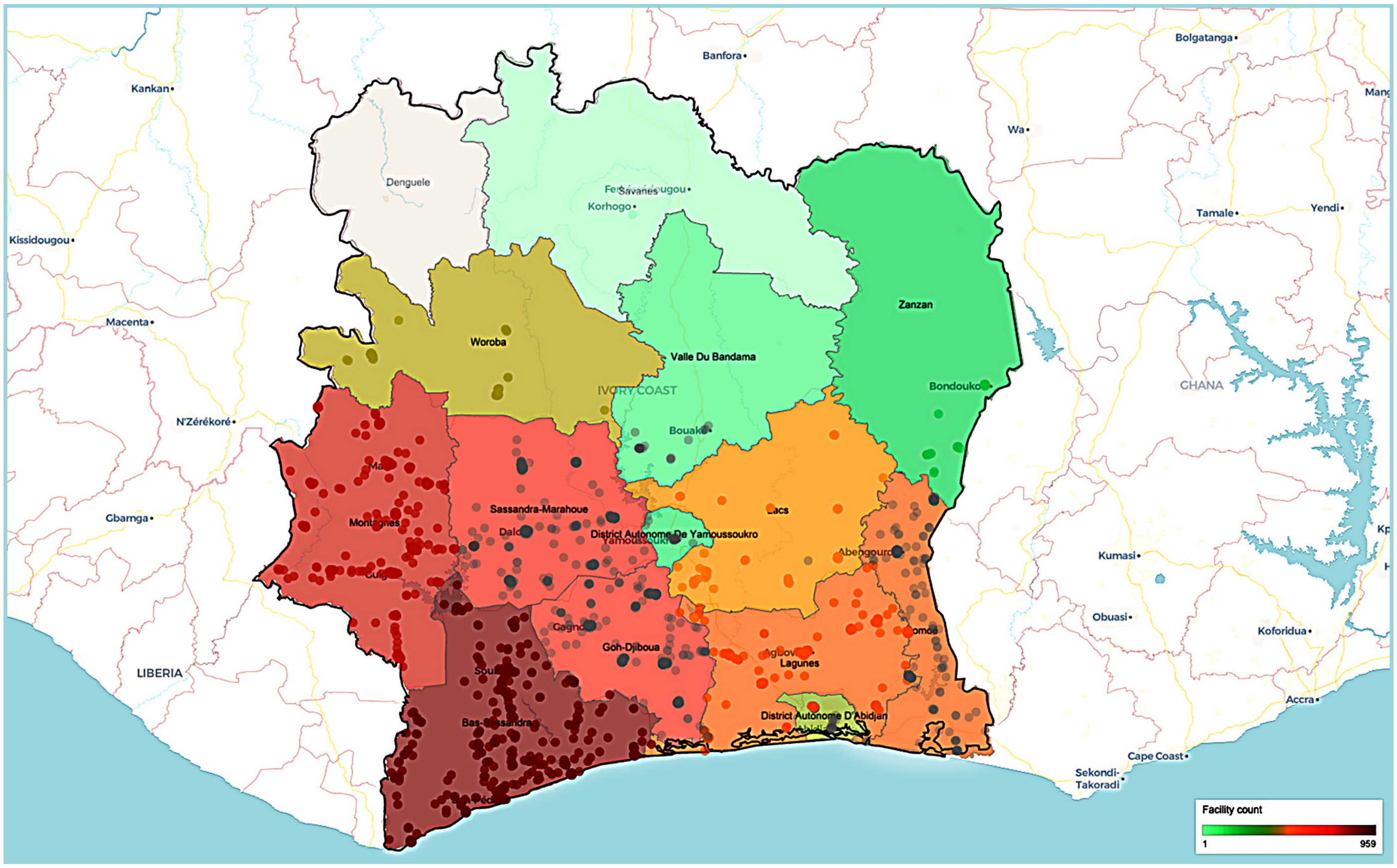


Figure 4. Facility count (colour-coded) within each administrative district highlighting that Bas-Sasandra has the largest number of cocoa cooperative facilities.



Supply Shed Configuration and Overlap

Derived supply sheds are spatially extensive yet geographically constrained by road networks, terrain and hydrological features, as shown in Figure 5, page 9 (Foster and Pushak, 2010). Most supply sheds cluster between 100,000 and 200,000 hectares in area (Figure 6, page 9), reflecting feasible transport distances under current infrastructure conditions.

Significant spatial overlap occurs between neighboring cooperatives due to facility density in productive regions. Overlap is most pronounced in southern districts with dense road networks and high cocoa production. This structural feature has implications for exposure metrics, as multiple cooperatives may be associated with the same landscape conditions.

Table 3 (page 10) illustrates the scale and structural dominance of cocoa within inferred sourcing landscapes. Modelled supply sheds cover approximately 55% of national territory (excluding overlap), indicating the extensive spatial footprint of cooperative sourcing influence. Cocoa occupies approximately 69% of this area and 38% of national land area, highlighting the degree to which production landscapes are structurally dominated by a single perennial crop. The large average plot size further reflects landscape consolidation consistent with monoculture systems.

Figure 5. Actual supply shed size (ha), also highlighting the overlap of supply sheds

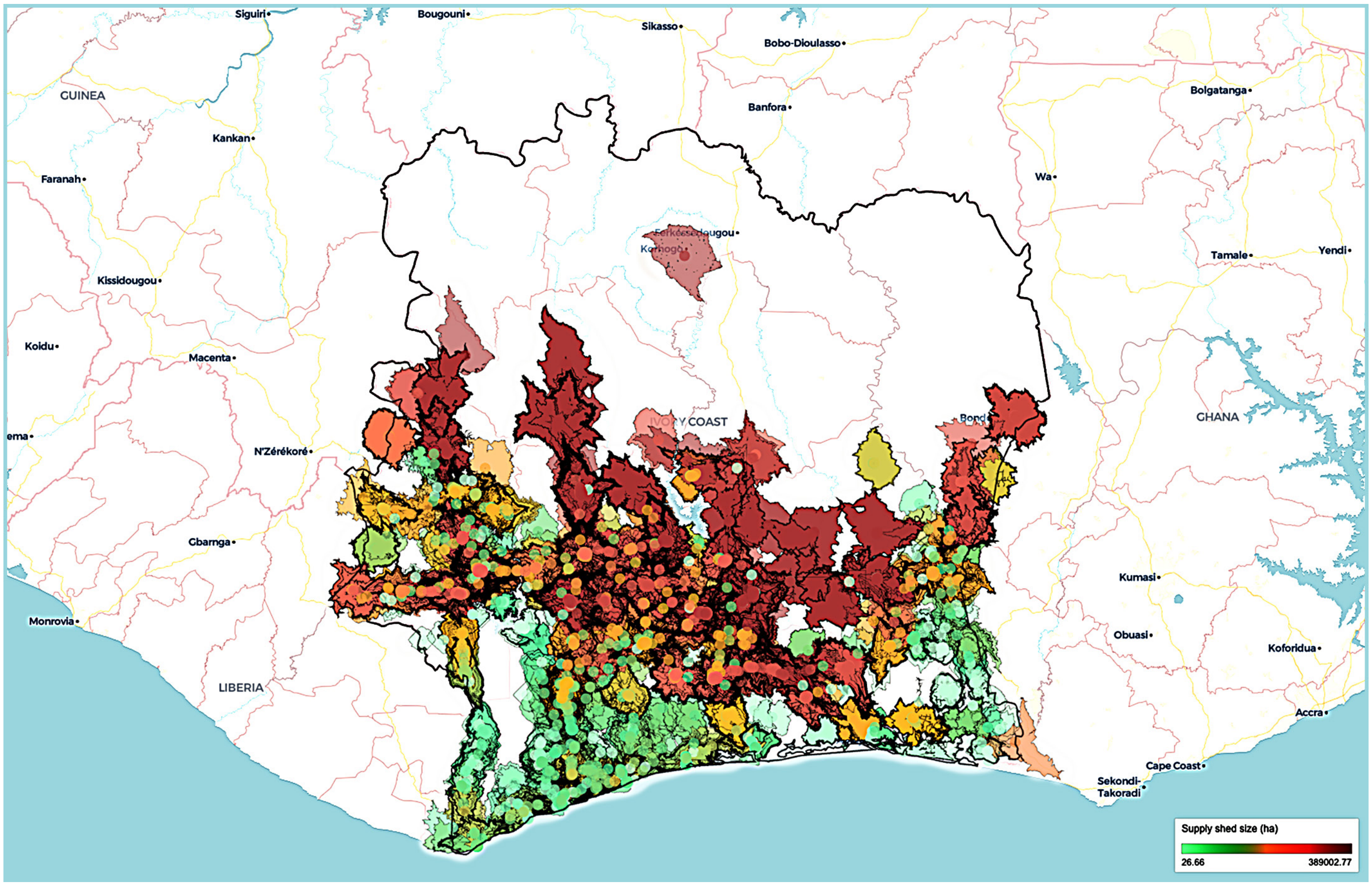


Figure 6. Collective supply shed size distribution (ha)

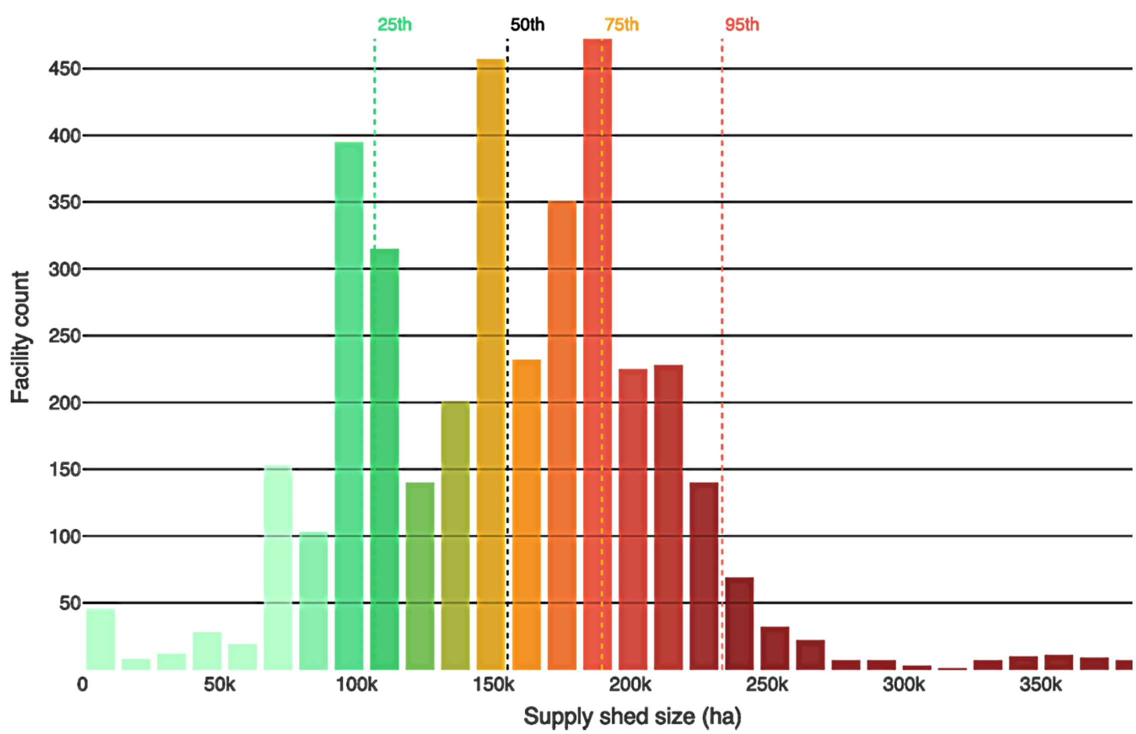


Table 3. Supply shed and commodity growing area statistics

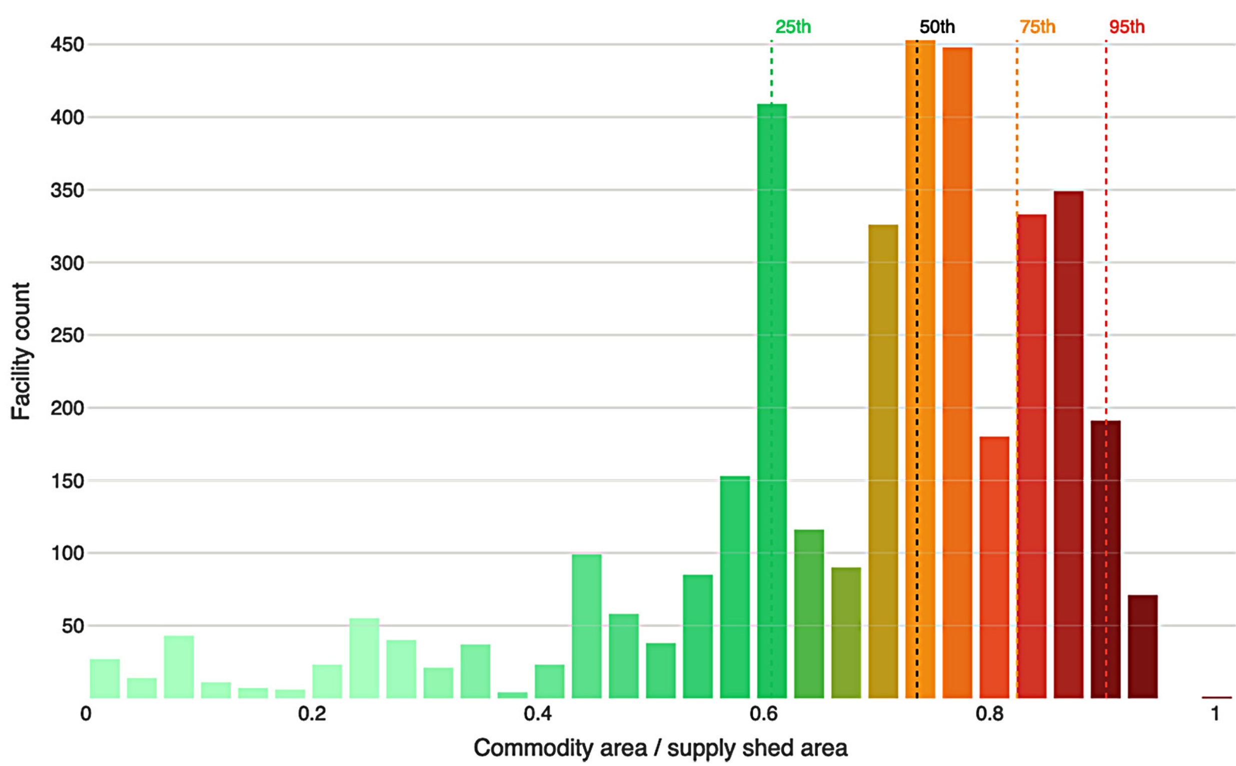
Indicator	Value	Context
Total Cooperative Facilities	3711	Distinct aggregation locations analyzed
Côte d'Ivoire Land Area	32.246 Mha	National land area reference
Total Supply Shed Area (non-overlapping)	17.59 Mha (55% of Land Area)	Modelled sourcing footprint
Total commodity growing area - 2023	12.14 Mha (2023) (69% of Supply Shed; 38% of Land Area)	Cocoa dominance within sourcing areas
Total Cocoa Plots (2023)	157,976	Contiguous homogenous cocoa patches
Average plot area	77 ha	Mean contiguous cocoa patch size

Cocoa Dominance within Sourcing Landscapes

Cocoa occupies a substantial share of inferred supply sheds. The upper quartile of sheds contains cocoa cover approaching or exceeding 80% of total area, indicating landscapes dominated by monoculture production systems (Figure 7, below).

This dominance reflects the structural integration of cocoa within southern Ivorian land-use systems and underscores the limited diversification of agricultural landscapes. Such concentration of a single perennial crop has implications for ecological resilience, pest susceptibility and long-term productivity.

Figure 7. Cooperative distribution of commodity growing/supply shed area ratios



Structural Implications

The spatial configuration of cooperatives and their supply sheds reveals three defining characteristics:

1. Geographic concentration in climatically suitable southern regions
2. High cooperative density near export infrastructure
3. Extensive monoculture dominance within sourcing territories

These structural features provide essential context for interpreting the distribution of environmental exposure analyzed in the following sections.

Distribution of Environmental Risk Exposure

This section examines the distribution of environmental exposure across cooperative supply sheds for each risk domain.

Non-Compliant Deforestation

Non-compliant deforestation exposure, defined as forest loss occurring after 31 December 2020 within modelled supply sheds, exhibits a strongly right-skewed distribution.

Mapping results (Figure 8, below) show that exposure is spatially concentrated in southern production corridors, particularly in districts with high cooperative density. The ranked facility curve (Figure 13) demonstrates a pronounced upper tail, with a relatively small number of cooperatives associated with the majority of post-2020 forest loss exposure. In contrast, median and lower-ranked facilities approach negligible values.

The histogram (Figure 10, page 12) distribution confirms this skew, with the majority of facilities clustered near zero exposure and a long tail of high-exposure outliers. This distributional structure suggests that exposure to non-compliant deforestation is unevenly distributed across cooperatives.

Figure 8. Non-compliant deforestation area (ha) within each cooperative supply shed

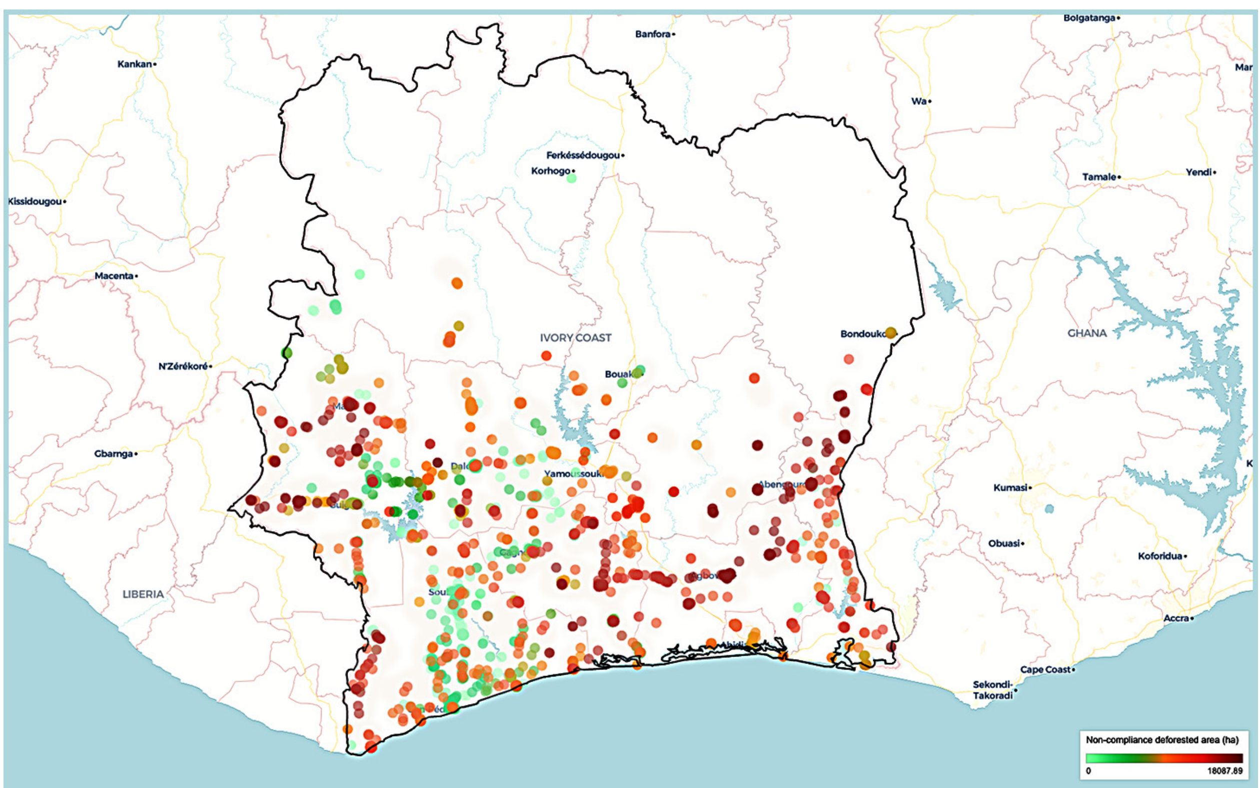


Figure 9. Non-compliant deforestation area (ha) ranked for cooperative facility supply shed

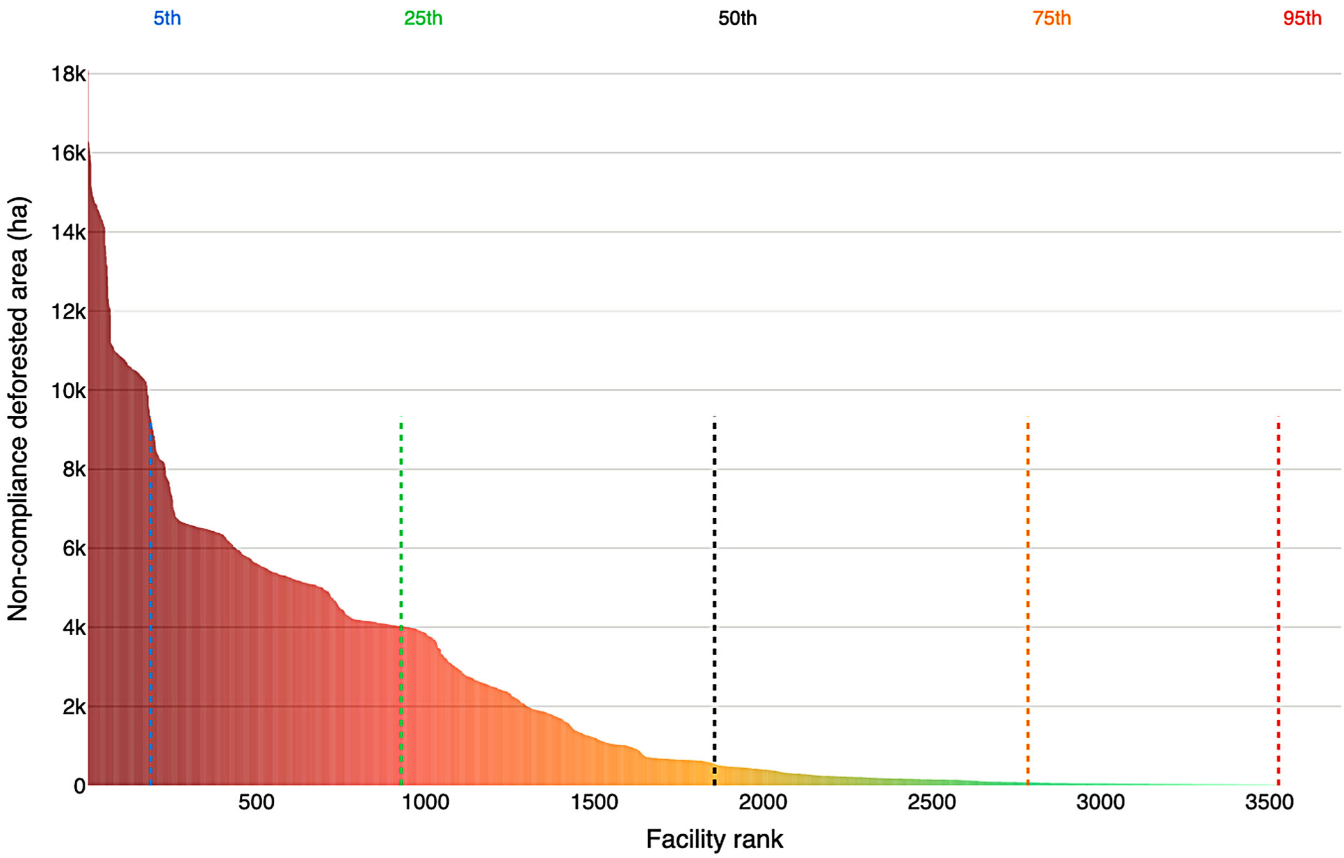
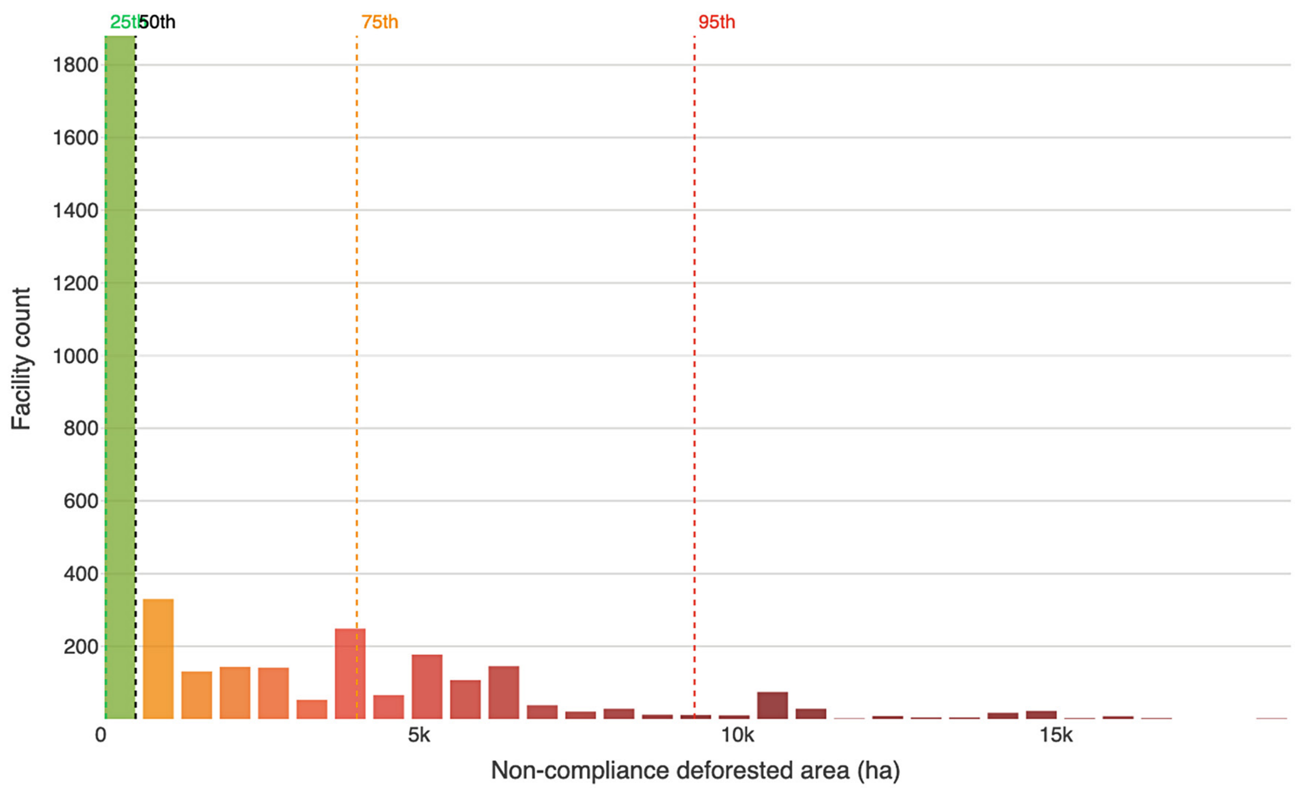


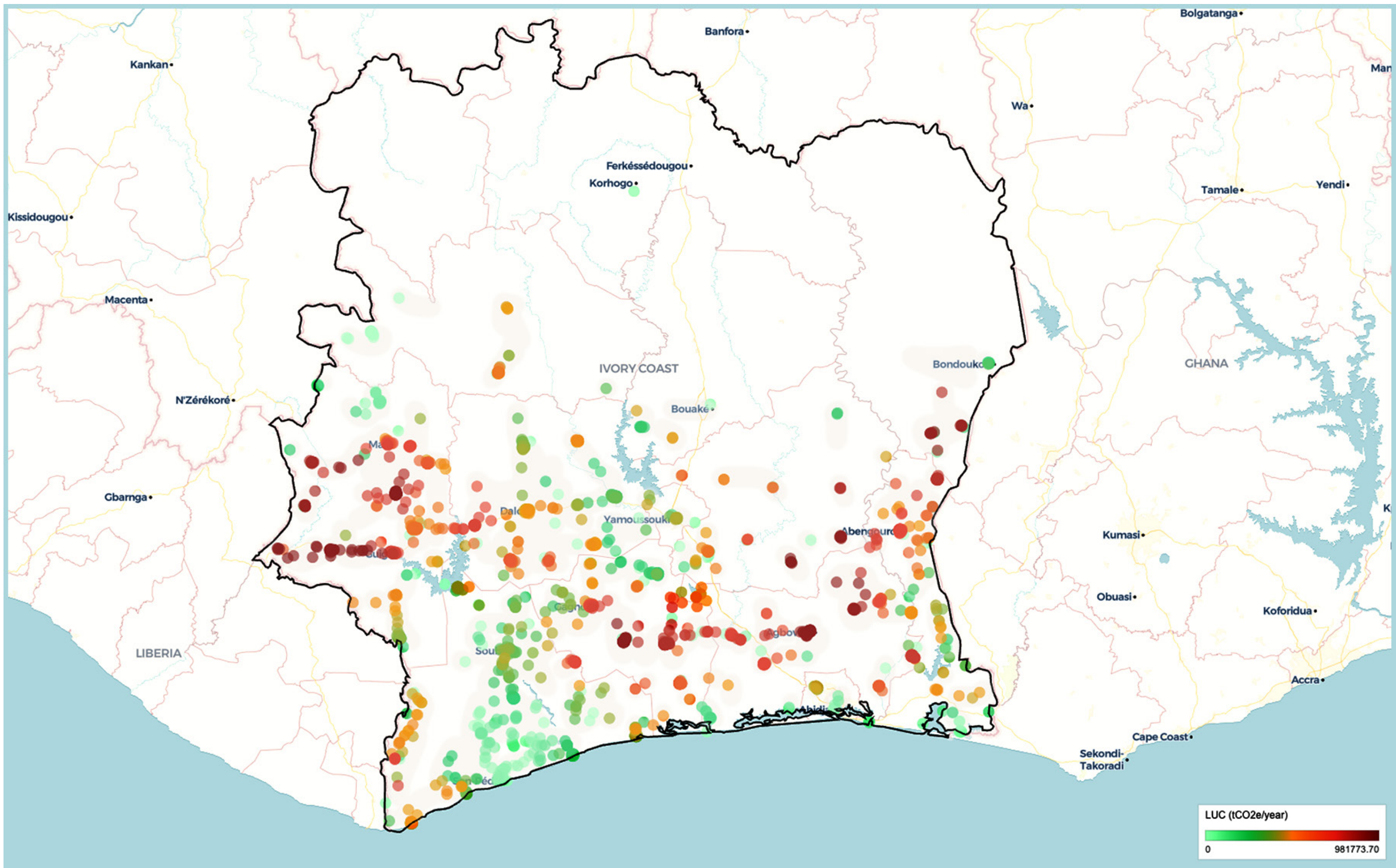
Figure 10. LUC Emissions statistical distribution (tCO2e / year)



Land-Use Change (LUC) Emissions

LUC emissions, derived from above-ground biomass loss on converted land, closely mirror deforestation patterns. Because forest conversion is the primary driver of LUC emissions, spatial exposure patterns are strongly correlated with post-2020 deforestation (Figure 11, below).

Figure 11. LUC Emissions (tCO2e / year)



While national-level LUC emissions have declined relative to historical peaks[10] facility-level exposure remains uneven. Ranked distribution curves (Figure 12, page 14) reveal a persistent high-emissions tail, indicating that a subset of supply sheds accounts for a disproportionate share of total LUC exposure, which is confirmed in the histogram in Figure 13 (page 14).

Figure 12. Cooperative facility rank - LUC Emissions (tCO2e / year)

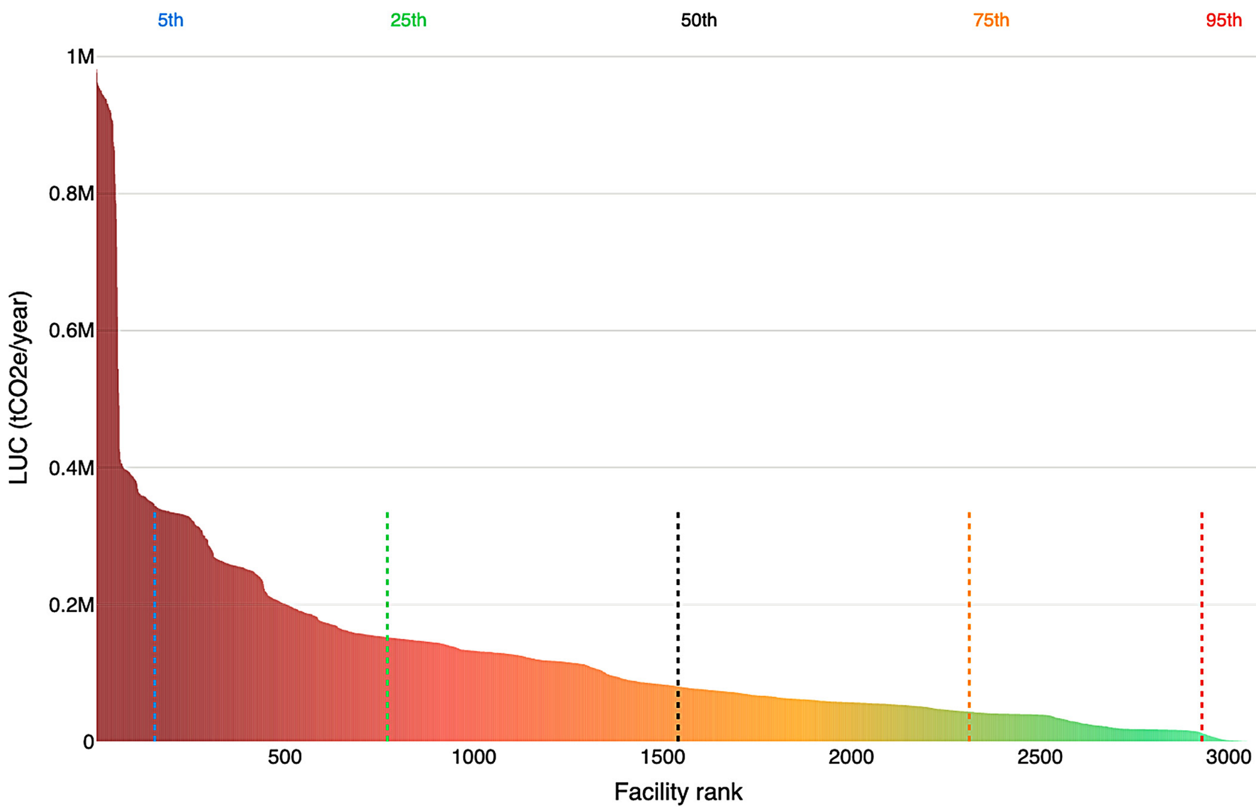
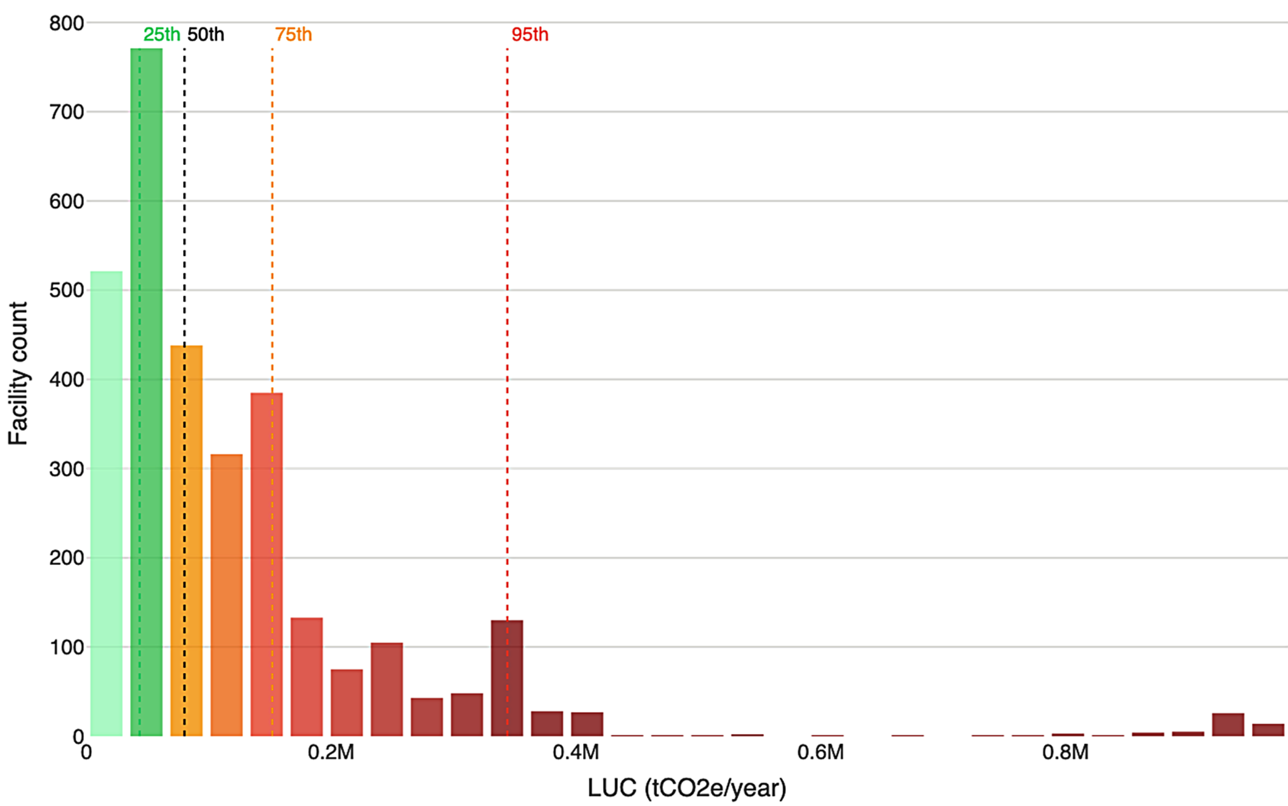
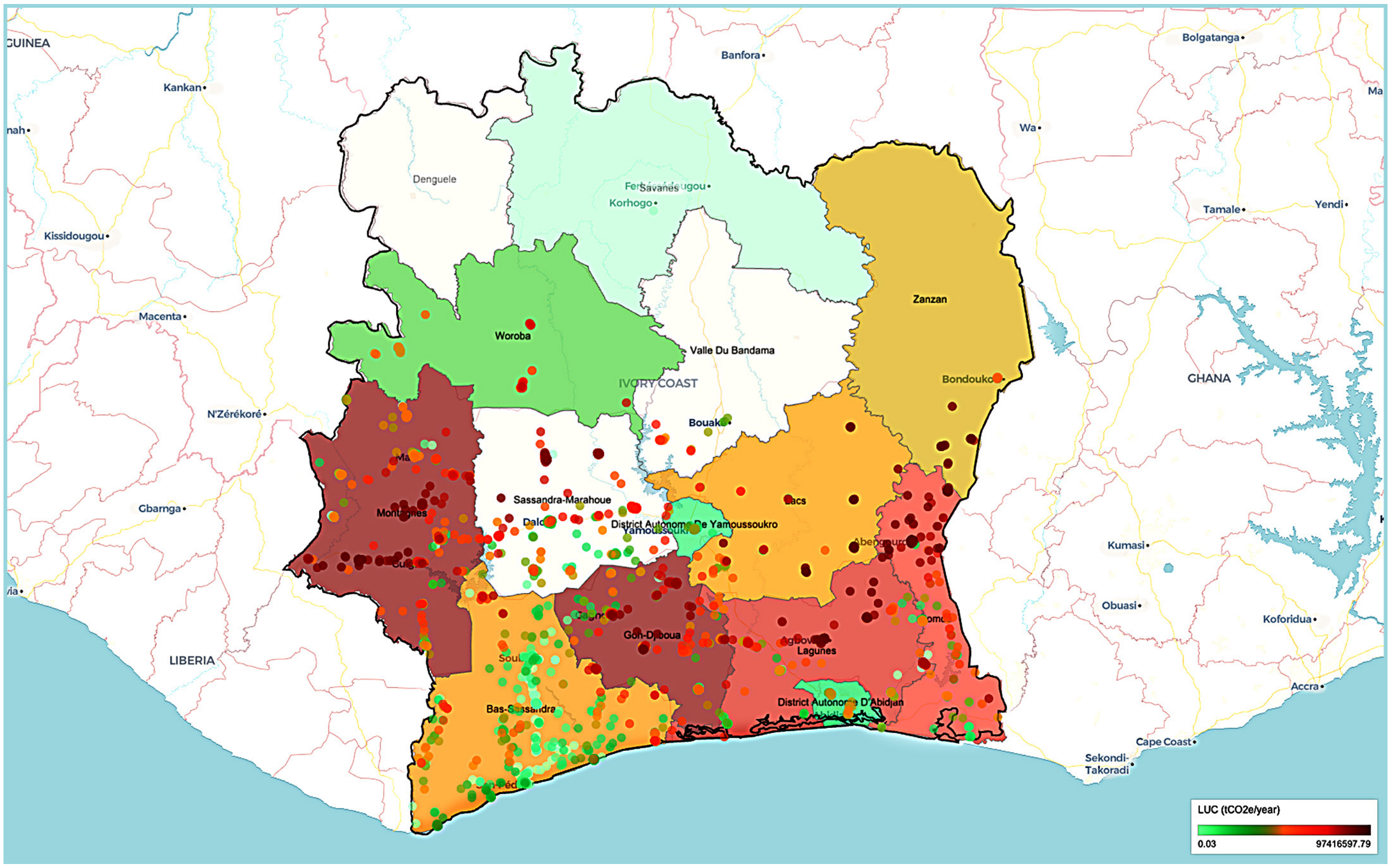


Figure 13. LUC Emissions statistical distribution (tCO2e / year)



At the district level, elevated LUC exposure aligns with previously identified deforestation hotspots, reinforcing the spatial coherence of carbon-related land-use risks.

Figure 14. LUC Emissions aggregated at the district level (tCO2e / year)

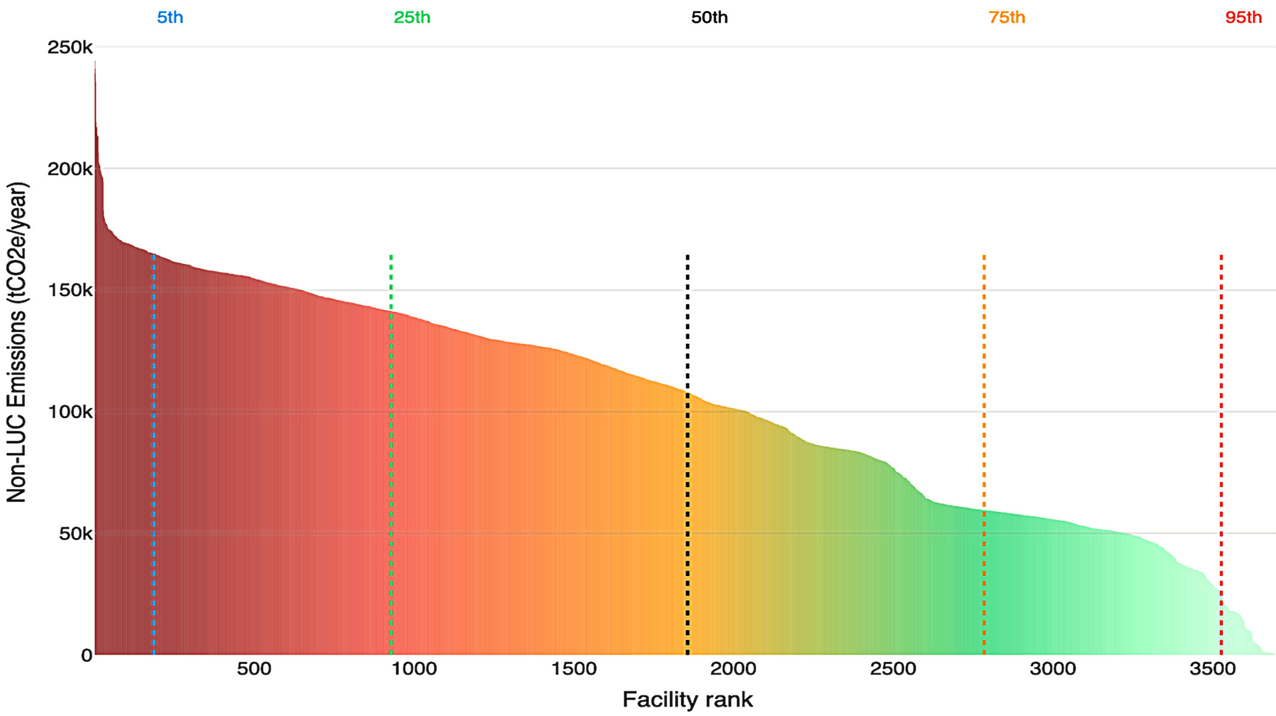


Non-LUC Emissions

Non-LUC emissions scale more gradually with commodity production intensity and logistics activity. Unlike land-use change emissions, these emissions do not exhibit pronounced right-skew or sharp discontinuities.

The ranked distribution curve in Figure 15 (page 15) shows a smoother gradient across cooperatives, reflecting incremental variation rather than step-change land conversion events. As such, non-LUC emissions represent a broad sectoral efficiency challenge rather than a hotspot-driven exposure pattern.

Figure 15. Cooperative facility rank - Non-LUC Emissions (tCO2e/year)

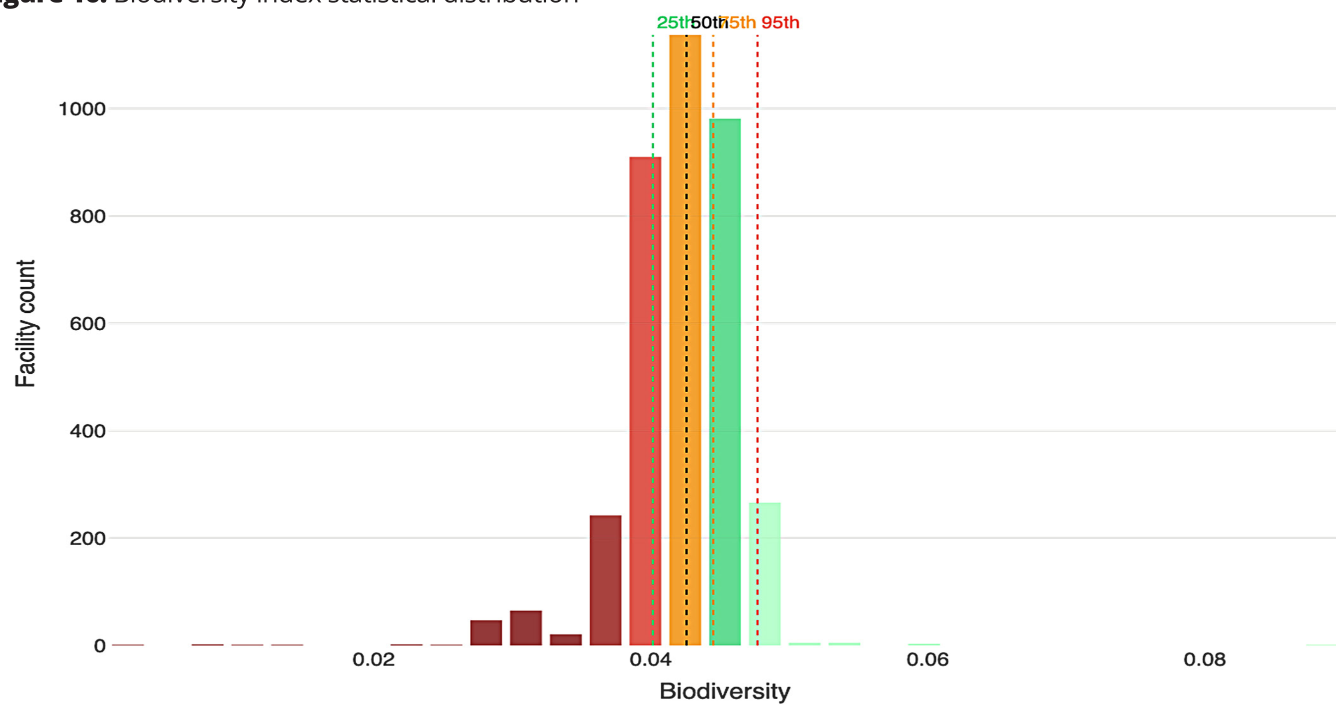


Biodiversity and Ecosystem Health

Biodiversity exposure, measured using canopy height heterogeneity (Rao's Q), is uniformly low across cocoa-associated supply sheds. No facility exceeds a Rao's Q value of 0.1. Under this index, values below approximately 0.3 are generally interpreted as indicating low functional diversity consistent with simplified or monoculture-dominated landscapes.

The statistical distribution (Figure 16 below) exhibits minimal dispersion between cooperatives, with no pronounced upper tail. This indicates that biodiversity degradation is broadly distributed rather than concentrated in isolated sourcing areas.

Figure 16. Biodiversity index statistical distribution



Water Stress

The meteorological water stress index indicates moderate but widespread hydrological pressure across cocoa supply sheds. The histogram (Figure 17 below) shows values tightly clustered around the median, while the ranked facility curve (Figure 18, page 18) exhibits a smooth gradient with no pronounced upper tail. Together, these patterns indicate limited dispersion and the absence of significant outliers.

Although overall inequality is low, spatial differentiation is evident (Figure 19, page 18). Water stress exposure increases inland toward drier northern regions and correlates with population density and climatic variability (Gnamien et al., 2021; World Bank, 2018). These patterns suggest structural climatic and hydrological constraints rather than cooperative-specific anomalies.

Figure 17. Cocoa collective water stress index histogram

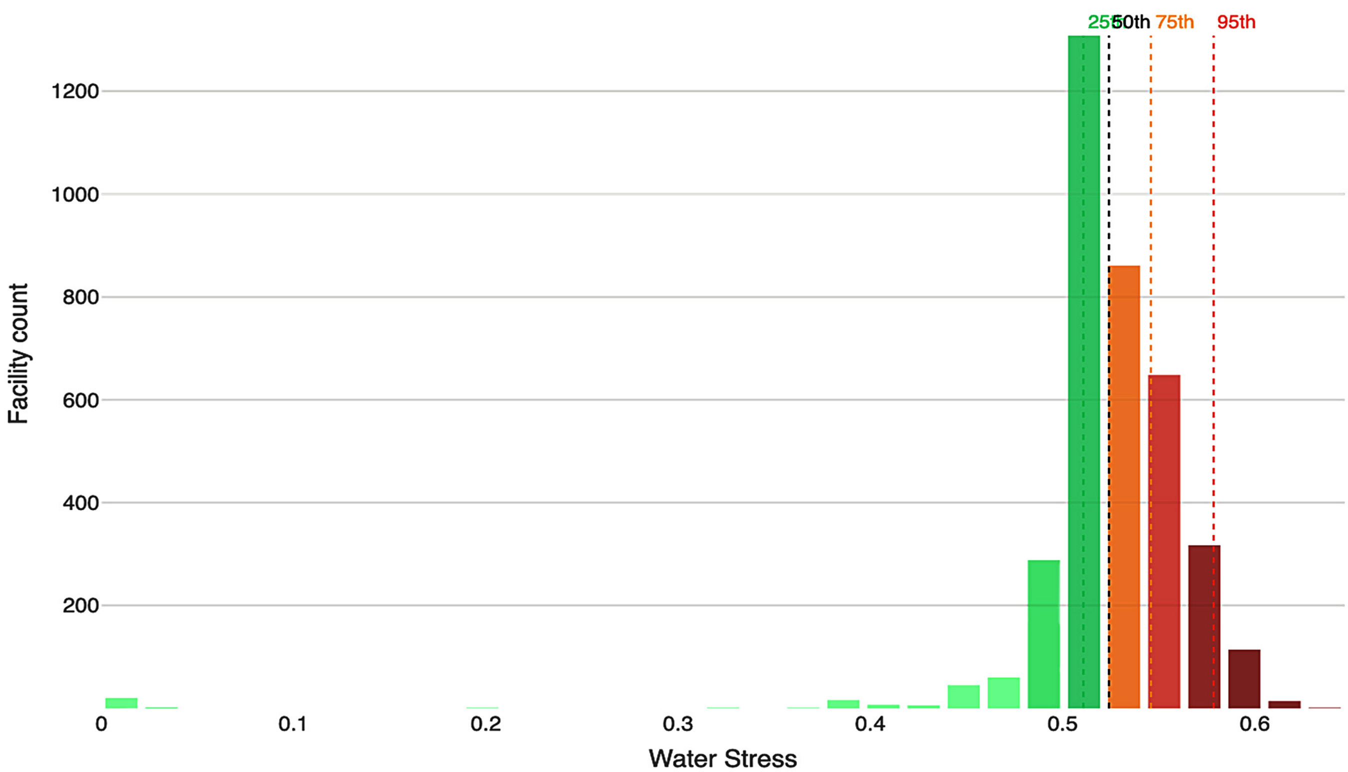


Figure 18. Cocoa collective facility rank location water stress index

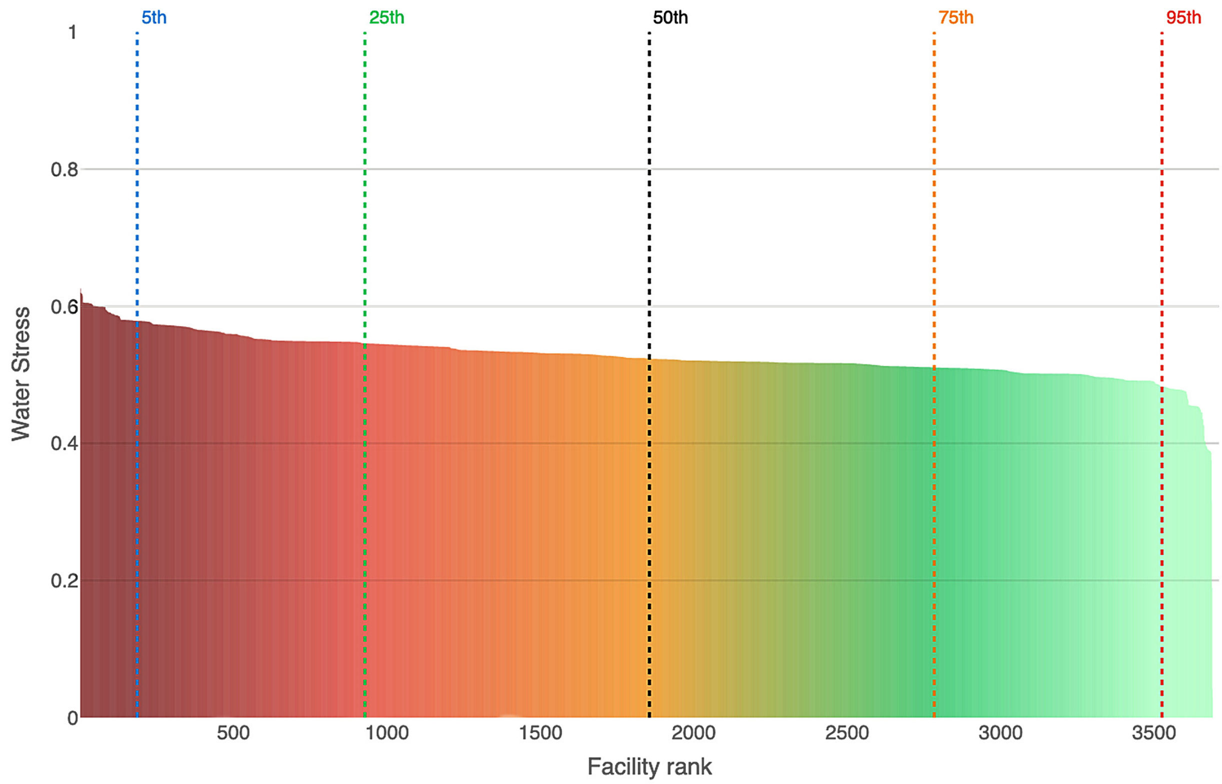
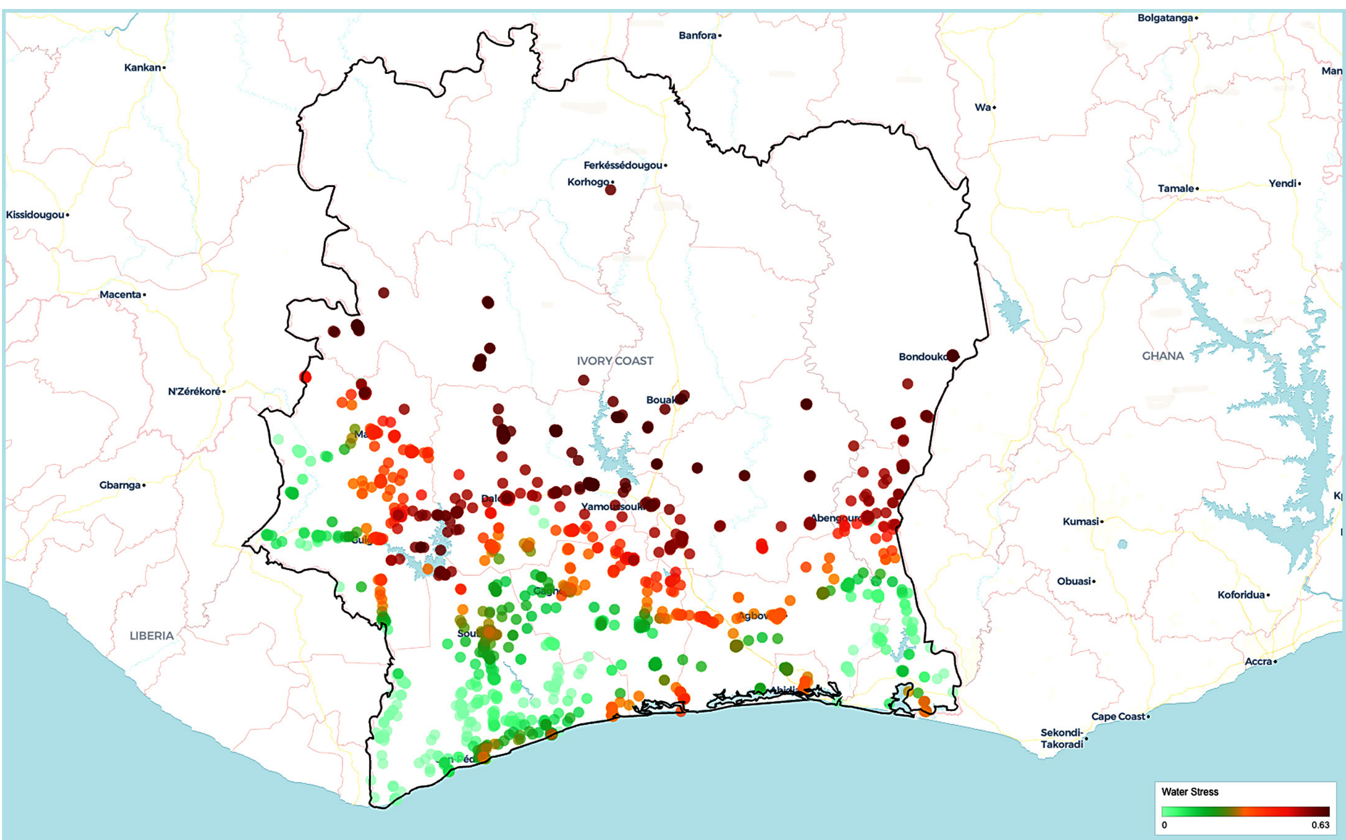


Figure 19. Cocoa collective location water stress index



Composite Risk Screening

To support comparative prioritization across cooperatives, a composite risk score is calculated as the equal-weighted mean of percentile-ranked components (see Analytical Framework: Geospatial Supply Shed Approach, page 4). The resulting distribution forms a continuous gradient without clear clustering into discrete risk classes (Figure 20 below).

The ranked composite curve in Figure 21 (page 20) highlights an upper tail of cooperatives with elevated combined exposure across multiple domains. These facilities represent candidates for prioritised engagement under a risk-based intervention framework.

However, it is important to note that the composite score blends both concentrated (deforestation and LUC emissions) and systemic biodiversity and water stress) metrics. It should therefore be interpreted as a relative screening tool rather than as an indicator of concentrated environmental impact.

Aggregation of the composite score at the district level (Figure 22, page 20) enables prioritization at a regional governance scale. District-level assessment allows engagement strategies to align not only with individual cooperatives but also with sub-national planning, enforcement and landscape management contexts. Districts such as Bas-Sassandra and Montagnes exhibit the highest combined risk scores when aggregated across facilities. In the case of Bas-Sassandra, this elevated district-level score reflects the cumulative effect of a high density of cooperatives rather than uniformly high facility-level risk, illustrating how structural production concentration can amplify regional exposure profiles.

Figure 20. Overall risk score facility count distribution

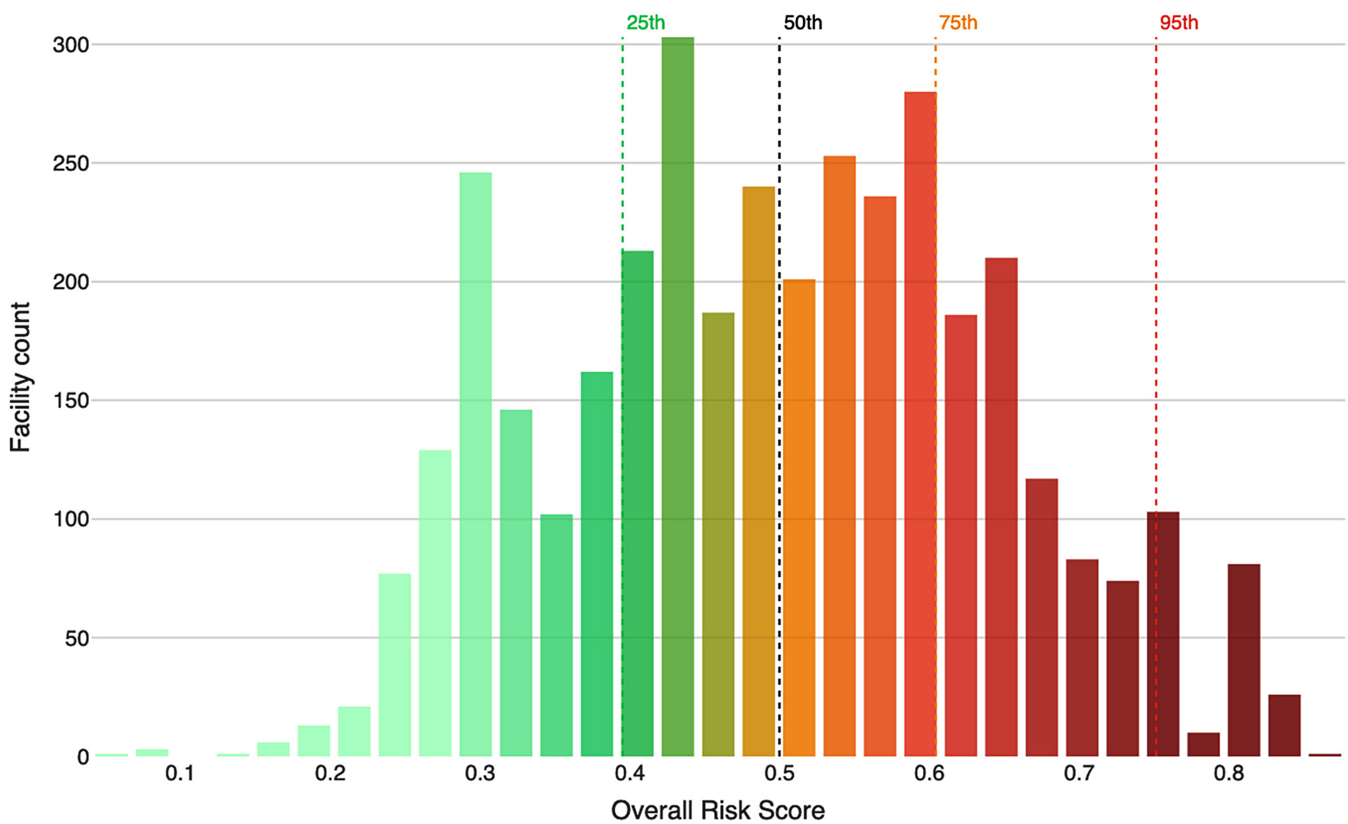


Figure 21. Overall Risk Score ranking

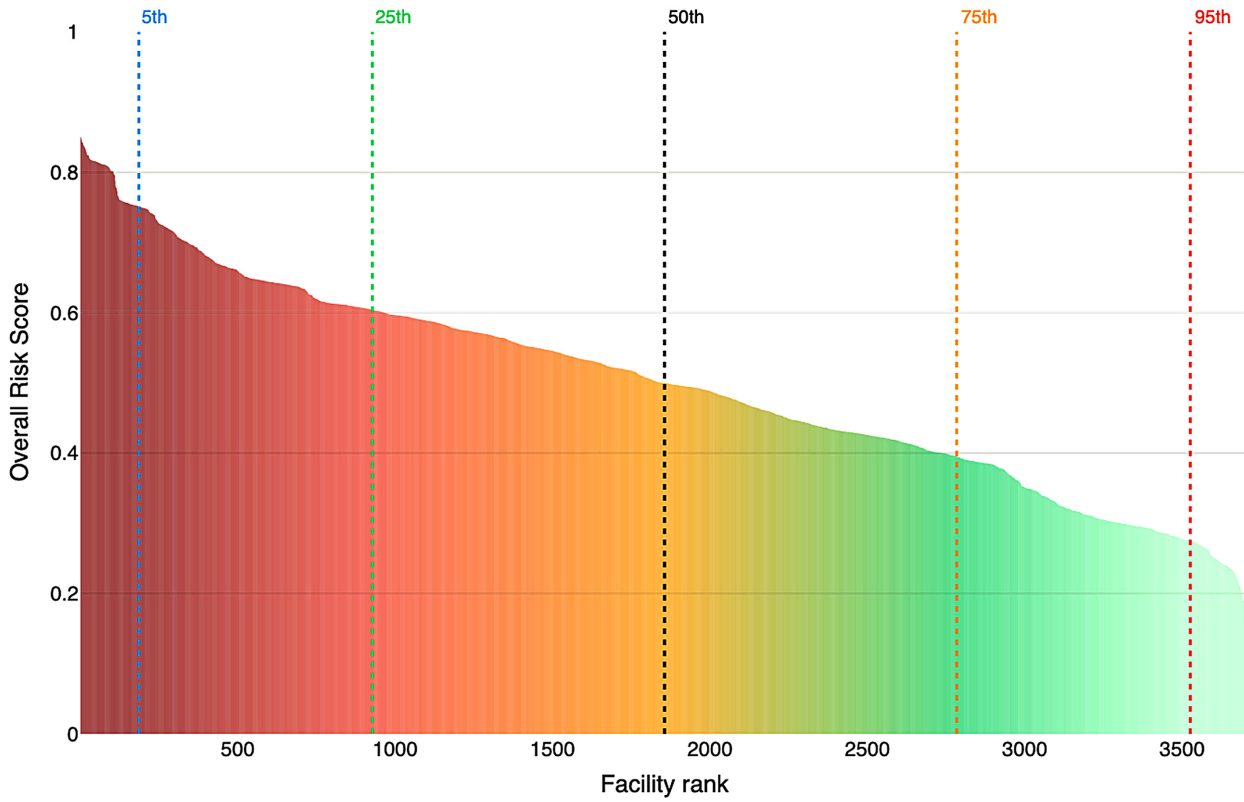
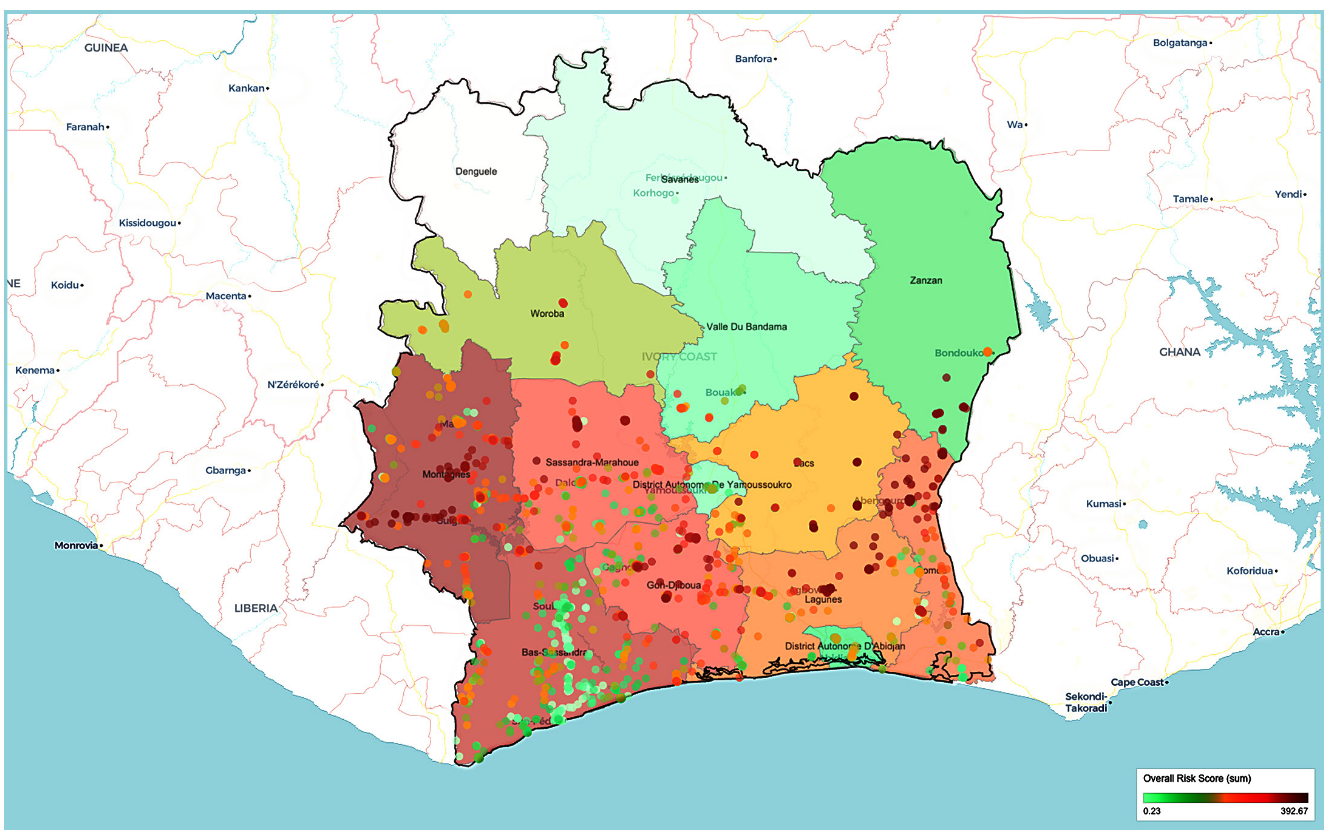


Figure 22. Summed risk score per facility within each administrative district



Discussion

Quantifying concentration

In accordance with the aims of the *Codex Planetarius* initiative, this analysis evaluates not only environmental exposure but its distribution across cooperatives. Table 4 below reports concentration ratios (CR5, CR10 and CR20) and Gini coefficients for four key metrics: deforestation, land-use change (LUC) emissions, biodiversity and water stress.

Table 4. Concentration Ratios and Gini coefficients for environmental metrics

Metric	Concentration Ratio			Gini Coefficient	Interpretation
	CR5	CR10	CR20		
Deforestation (non-compliant)	24.8%	41.4%	64.2%	0.652	Highly concentrated
LUC Emissions	22.9%	35.3%	53.3%	0.492	Moderately concentrated
Biodiversity	5.1%	10.1%	20.1%	0.002	Systemic
Water Stress	5.6%	11.0%	21.6%	0.031	Systemic / Low inequality

Concentration ratios indicate the share of total exposure associated with the top 5%, 10% and 20% of cooperatives ranked by exposure. The Gini coefficient summarises inequality across all cooperatives on a scale from 0 (perfect equality) to 1 (maximum inequality). Originally developed to measure income inequality, the Gini coefficient has been widely applied to environmental distributions, including assessments of ecological and "green" inequality (Martin and Conway, 2025).

Due to overlapping supply sheds, these statistics reflect exposure within modelled sourcing areas rather than uniquely attributed landscape totals. Concentration patterns may partly reflect geographic clustering of cooperatives within high-risk landscapes and variation in supply shed size, which can mechanically amplify exposure where facility density is high. The reported metrics therefore describe how environmental risk is distributed under current sourcing configurations; they do not constitute causal attribution of landscape-level impact.

Concentrated Carbon Risk and Targeted Intervention

The results demonstrate substantial inequality in exposure to non-compliant deforestation and LUC emissions. As shown in Table 4, the top 20% of cooperatives account for 64.2% of total exposure to non-compliant deforestation and 53.3% of total exposure to LUC emissions. The corresponding Lorenz curves (Figures 23 and 23, page 22) exhibit pronounced curvature away from the line of equality, reinforcing the presence of a concentrated upper tail.

This distributional structure indicates that carbon-related land-use exposure is disproportionately associated with a minority of cooperatives. From an intervention perspective, such concentration suggests that targeted engagement with high-exposure actors may yield material reductions in aggregate carbon-related risk. This aligns with the *Codex Planetarius* principle of prioritizing the least efficient or highest-impact production systems.

Figure 23. Lorenz curve for non-compliant deforestation

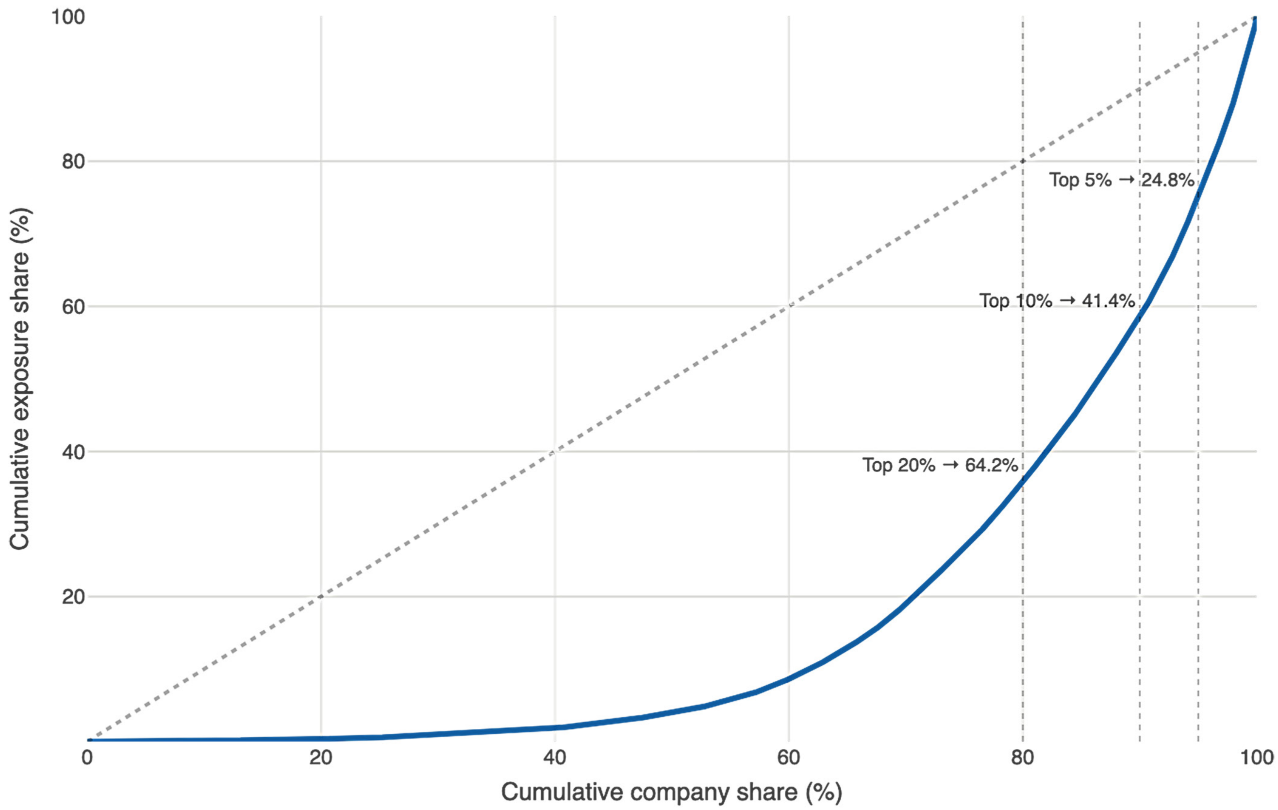
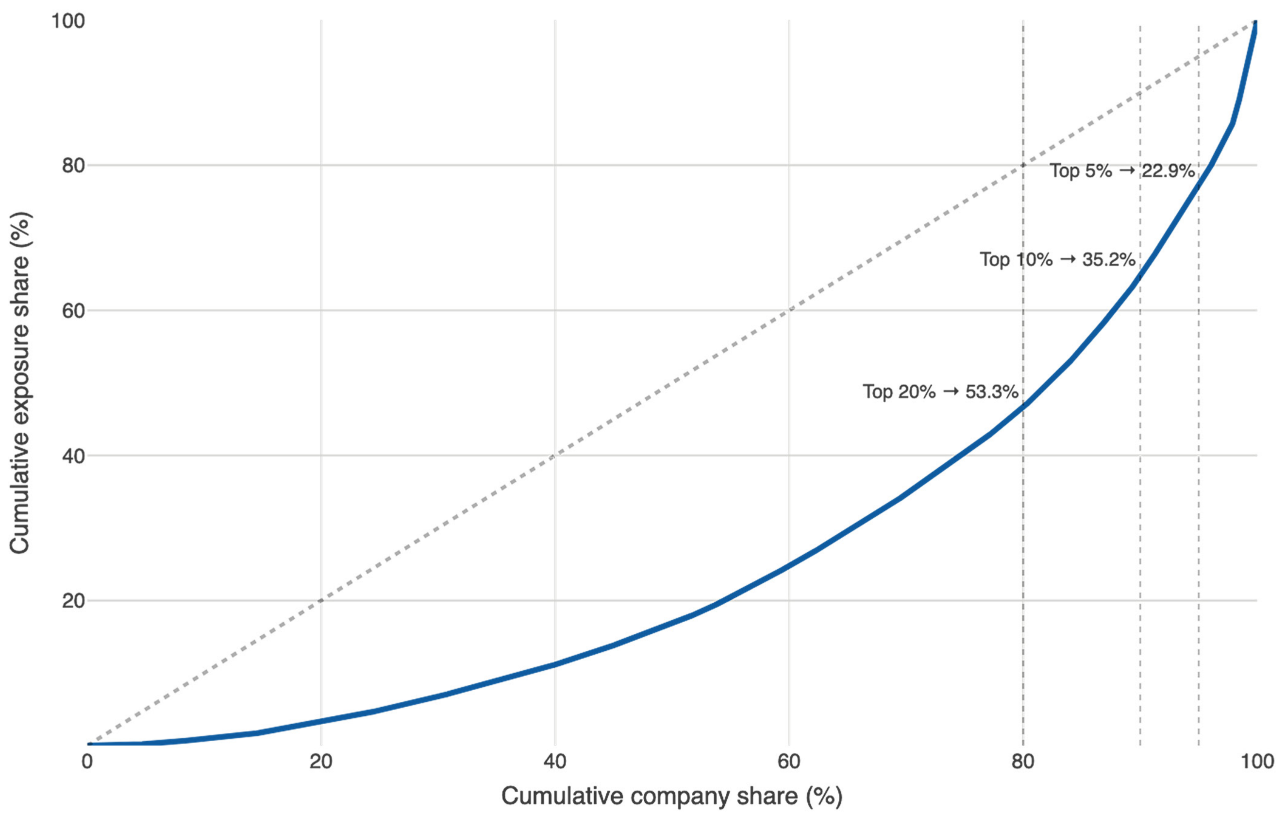


Figure 24. Lorenz curve for LUC emissions



Systemic Ecological and Hydrological Stress

In contrast, biodiversity and water stress exhibit negligible to very low inequality across cooperatives. The Gini coefficient for biodiversity exposure is 0.002, while water stress is 0.031 (Table 4, page 21). The Lorenz curves for these indicators lie close to the line of equality, indicating limited dispersion between facilities.

These patterns suggest that biodiversity degradation and hydrological stress are systemic rather than concentrated. The majority of cooperatives fall within a narrow exposure range, reflecting structural landscape conditions shaped by monoculture dominance, historical land conversion and climatic gradients. While overall inequality in water stress exposure is low, spatial differentiation remains evident, with higher exposure observed inland toward the drier northern regions and in areas correlated with population density (Gnamien et al., 2021).

The distinction between concentrated carbon-related land-use risk and systemic ecological stress has important policy implications. Whereas deforestation and LUC emissions may be addressed through targeted compliance and engagement strategies, biodiversity degradation and water stress require coordinated, landscape-scale interventions extending beyond individual cooperatives.

Structural Configuration and Regional Amplification

The concentration of cooperatives in southern production corridors, particularly in Bas-Sassandra and adjacent districts, reinforces the importance of structural landscape configuration in shaping exposure patterns. High cooperative density and overlapping supply sheds create cumulative regional exposure profiles, even where average facility-level risk remains moderate.

District-level aggregation of composite risk scores illustrates how production density can amplify regional exposure. In Bas-Sassandra, elevated district-level risk reflects the cumulative effect of numerous cooperatives operating within ecologically simplified landscapes rather than uniformly extreme facility-level values.

This multi-scalar perspective highlights the importance of aligning cooperative-level engagement with jurisdictional governance mechanisms, including district-level enforcement, land-use planning and restoration initiatives. Structural configuration therefore mediates how concentrated and systemic risks manifest spatially.

Methodological Considerations

Several methodological considerations are relevant to interpretation.

First, supply sheds are modelled probabilistic territories and may overlap spatially. Environmental metrics therefore represent exposure within sourcing landscapes rather than exclusive or uniquely attributed impact.

Second, concentration metrics describe the distribution of exposure across cooperatives under current sourcing configurations. They do not imply direct causal responsibility for landscape-level environmental change.

Third, the composite risk score blends concentrated and systemic dimensions and is intended as a screening tool rather than an absolute measure of ecological harm.

Despite these limitations, the framework provides a consistent and scalable approach for linking cooperative aggregation points to spatial environmental indicators, supporting comparative prioritization and multi-scalar governance alignment.

Conclusions

This analysis demonstrates how geospatial intelligence can operationalize the *Codex Planetarius* vision by linking facility-level supply sheds to environmental performance metrics that are transparent, comparable and scalable. By moving beyond national averages to spatially explicit exposure profiles, the approach provides a foundation for evidence-based engagement across global cocoa supply chains.

The concentration of deforestation and LUC emissions among a minority of cooperatives suggests that rapid environmental gains are achievable through focused intervention. Consistent with *Codex* principles, prioritizing the least efficient or highest-impact production systems can accelerate progress while creating clear performance benchmarks for the sector.

At the same time, the near-uniform distribution of biodiversity degradation and water stress highlights the structural transformation required within cocoa landscapes. Low Rao's Q diversity values and widespread hydrological stress signal ecosystems in decline. These findings reinforce the need for integrated landscape management, agroforestry expansion, soil and water conservation, and alignment between national development planning and ecosystem restoration goals.

Planned infrastructure expansion and increasing processing capacity may intensify production pressures unless accompanied by strong land governance, yield optimization on existing farmland, and strict avoidance of further natural forest conversion. Ensuring that economic development proceeds within ecological limits will be essential to safeguarding Côte d'Ivoire's remaining natural capital and the long-term viability of its cocoa sector.

While overlapping supply sheds mean the results represent exposure rather than uniquely attributed impact, the concentration patterns remain highly relevant for prioritization and collective action. The framework presented here provides a scalable blueprint for extending *Codex*-aligned assessments to other commodities and geographies, supporting WWF's broader mission to conserve nature while enabling sustainable production and trade.

Footnotes

1 https://www.kakaoplattform.ch/about-cocoa/cocoa-facts-and-figures

2 https://oec.world/en/profile/country/civ

3 https://www.reuters.com/markets/commodities/ivory-coasts-mid-crop-cocoa-output-expected-drop-around-40-due-long-drought-2025-03-18

4 https://www.reuters.com/world/africa/ivory-coasts-main-cocoa-harvest-decline-sharply-third-consecutive-year-sources-2025-11-20/

5 https://developers.google.com/earth-engine/datasets/catalog/projects_forestdatapartnership_assets_cocoa_model_2025a

6 https://developers.google.com/earth-engine/datasets/catalog/ESA_WorldCereal_AEZ_v100

7 https://developers.google.com/earth-engine/datasets/catalog/GOOGLE_SATELLITE_EMBEDDING_V1_ANNUAL

8 https://www.unisco.com/international-ports/san-pedro-cote-divoire

9 https://www.trade.gov/market-intelligence/cote-divoire-port-san-pedro-expansion-and-modernization

10 https://climatechangetracker.org/nations/greenhouse-gas-emissions/cote-d-ivoire/progress-and-recent-impact

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