



Technical paper

Understanding risk drivers: Biomass loss attribution

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September 2025

Introduction

Understanding the **drivers of biomass loss** is essential for **managing risks** in carbon offset projects and **maintaining the credibility and resilience of carbon markets**. Carbon offset projects face risks from natural hazards such as fire and drought, as well as other activities including logging, agriculture, or disturbances such as insect outbreaks. Without clear attribution of these drivers, credit pricing, insurance, and mitigation strategies become unreliable. Attribution analysis **quantifies the contribution of each factor, providing the transparency required for effective risk management and generating trust in the market**.

This paper discusses attribution analysis applied to **70 REDD+, IFM, and ARR projects in the Amazon basin**. The analysis combines 25 years of high-resolution Chloris biomass data with detailed fire and drought exposure. By separating natural risk factors at the project level, the methodology enables accurate risk pricing, supports efficient insurance design, and informs targeted mitigation planning, which is increasingly critical as climate change intensifies fire and drought risks.

What is attribution analysis

Attribution analysis **distinguishes biomass loss drivers** by separating natural hazards such as fire, drought, and wind from other drivers such as logging, agriculture, shifting cultivation, or disturbances like insect damage. Using regression methods, it **quantifies how much of the observed loss can be explained by each contributing factor**, as shown in Box 1.

This separation of drivers is critical for risk mitigation and insurance assessment. Accurate attribution ensures risks are priced appropriately, mitigation measures are well targeted, and insurance coverage remains credible.

Box 1. Biomass loss attribution to different drivers

Biomass loss can be expressed as a sum of contributing drivers and an error term ε :

$$\begin{aligned} \text{Biomass Loss} = & \beta_1 \\ & \cdot \text{Fire Exposure} \\ & + \beta_2 \\ & \cdot \text{Drought Exposure} \\ & + \beta_0 \cdot \text{Other Drivers} + \varepsilon \end{aligned}$$

where:

Biomass Loss: The observed annual decrease in biomass for a project and year, based on the Chloris dataset.

β_1 x Fire Exposure: Biomass loss directly attributable to fire events., indicating project vulnerability to fire-related disturbances.

β_2 x Drought Exposure: Biomass loss directly attributable to drought conditions, including delayed impacts from previous years.

β_0 x Other Drivers: Captures biomass changes not explained by fire or drought, such as logging, agriculture or cultivation shifts and other disturbances (e.g.. nests).

Attribution analysis provides strategic perspectives **for buyers, project developers, and insurers** by enabling:



Risk understanding: Identifying specific causes of biomass loss allows project developers to tailor mitigation actions and strengthen resilience, such as building firebreaks or selecting drought-resistant species.



Market integrity: Transparent quantification of risk drivers builds confidence among carbon credit buyers and strengthens trust in project quality.



Insurance perspective: Attribution informs underwriting, enables accurate pricing, and supports efficient insurance solutions.

Our Approach

We analyzed **70 REDD+, IFM, and ARR projects¹** across the **Amazon basin** using 25 years of Chloris biomass data combined with historical fire and drought exposure. For each project and year, we calculated biomass loss and used attribution analysis to determine whether it was driven by fire, drought, or other factors, as illustrated in Figure 1.

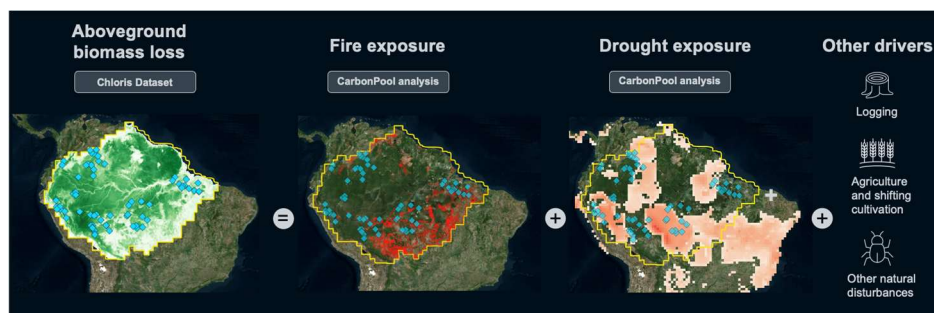
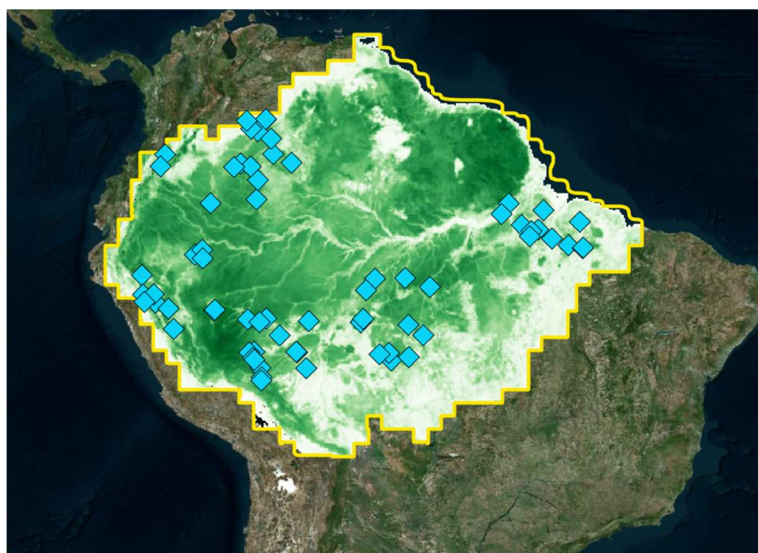


Figure 1. Illustration of the methodology. The attribution analysis quantifies both natural and anthropogenic drivers of biomass loss to support risk assessment and insurance solutions for carbon projects in the Amazon basin. Blue diamonds mark project locations, representing avoided deforestation, improved forest management, and afforestation projects. Each map is shown in increasing detail in subsequent images.

Step 1: Observation of biomass from space

We analyzed spatial maps of annual biomass observations from 2000 through 2024 using Chloris data to generate time series for each registered carbon project in the Amazon region, as illustrated in Figure 2.



¹ Shapefiles based on Karnik et al, 2025: <https://www.nature.com/articles/s41597-025-04868-2>

Figure 2. Example of Chloris biomass (stored amount) for 2024. Blue diamonds mark project locations in the Amazon basin, representing avoided deforestation, improved forest management, and afforestation projects.

Step 2: Exposure to fire

We evaluated each project's exposure to fire over the past 25 years by combining NASA FIRMS fire observations with a proprietary clustering algorithm. This algorithm groups fires according to local conditions, size, and intensity. As a result, only large, high-intensity events are classified as damaging, as shown in Figure 3.

It is also important to account for lagged exposure. Biomass loss caused by fire may not be immediately detected in satellite observations. The signal can appear with a delay of up to one year, which our analysis incorporates.

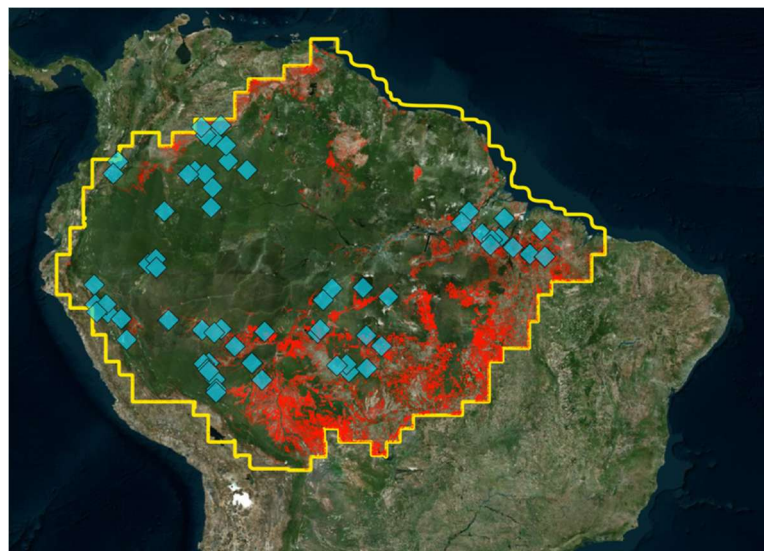


Figure 3. Exposure to fire. Red areas indicate fire clusters. Blue diamonds mark project locations in the Amazon basin.

Step 3: Exposure to drought

We assessed exposure to drought using the Standardized Precipitation Evapotranspiration Index (SPEI), illustrated in Figure 4. Drought conditions in the current year, as well as in the preceding two years, can contribute to biomass loss. Our attribution analysis therefore incorporates lagged drought effects to capture these delayed impacts.

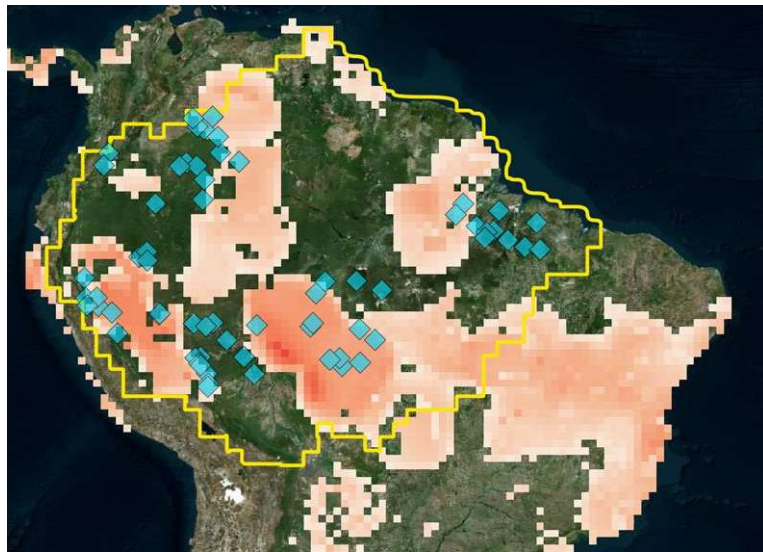


Figure 4. Example of spatial distribution of the SPEI drought index over the past 12 months indicating current drought conditions.

Step 4: Detection and attribution of biomass loss

To determine whether biomass declined compared to the previous year, we compared annual biomass values for each project and identified reductions relative to the prior year. We then quantified year-on-year biomass loss and attributed detected changes to potential drivers.

This involved examining fire, drought, and other disturbances, while accounting for lagged effects where events in prior years may influence subsequent declines. Time series of exposure were developed for each project using the proprietary fire clustering algorithm and the SPEI drought index, as illustrated in Steps 2 and 3. Ordinary least squares regression was then applied to quantify relationships between biomass loss and candidate drivers, enabling us to identify the most probable causes of each observed loss event.

Key drivers of biomass losses

Total biomass loss has increased since 2001, reflecting a parallel rise in overall biomass across the analyzed projects. In the early 2000s, nearly all biomass loss was attributed to other drivers such as logging, permanent agriculture, and shifting cultivation, as well as other disturbances like insect outbreaks (Figure 4).

In recent years, however, about 50 percent of projects with biomass loss were affected by natural hazards such as fire and drought, while the remainder were linked to anthropogenic drivers or other disturbances (Figure 5).

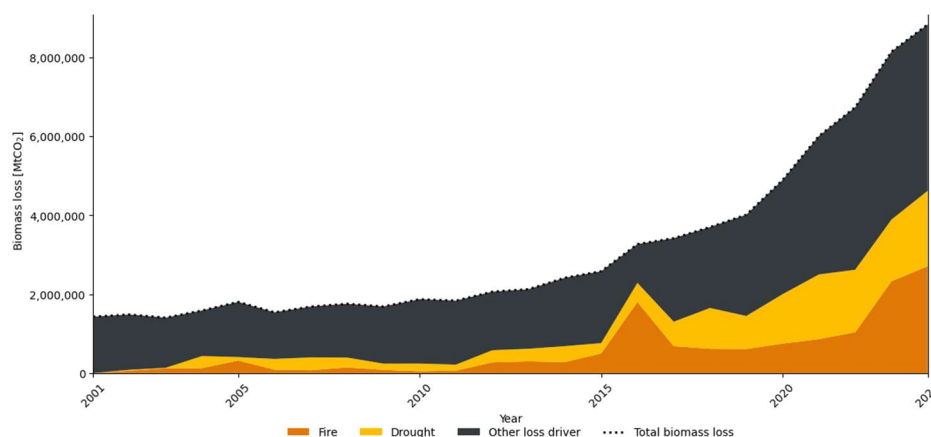


Figure 4. Biomass loss drivers over time for all projects. The stacked areas show the absolute contribution from fire, drought, and other drivers, with a dotted line indicating total biomass loss. Values are aggregated annually from 2001 through 2024.

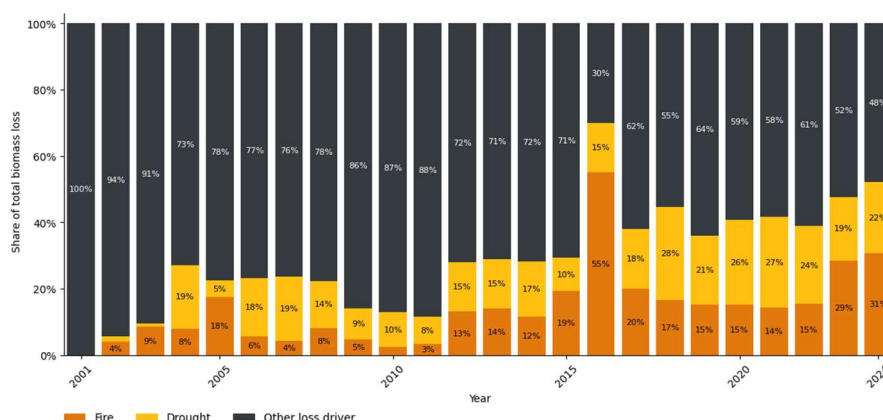


Figure 5. Relative contribution of biomass loss drivers by year. The stacked bars show the percentage share of fire, drought, and other drivers contributing to annual biomass loss across all projects in the Amazon basin from 2001 to 2024.

Resilience depends on project type



Afforestation projects are highly vulnerable to early-stage drought before forests mature, **while REDD+ and IFM projects** are more drought-resilient but remain exposed to large-scale fire damage. When drought and fire occur in the same year, biomass loss is amplified.

Unlocking insurance potential



Understanding the drivers of risk enables efficient insurance pricing. If developers can guarantee permanence of carbon credits through in-kind insurance, projects can attract more risk-averse sources of capital and unlock the full value of long-term offtake agreements.

Climate change intensifies natural hazard risks

Climate change projections for the next two decades, under both “most likely” and “worst case” scenarios, indicate increased fire exposure (Figure 6). This amplifies the risk of large-scale biomass loss events and underscores the growing need for permanence insurance and adaptation measures to avoid biomass losses due to natural hazards.

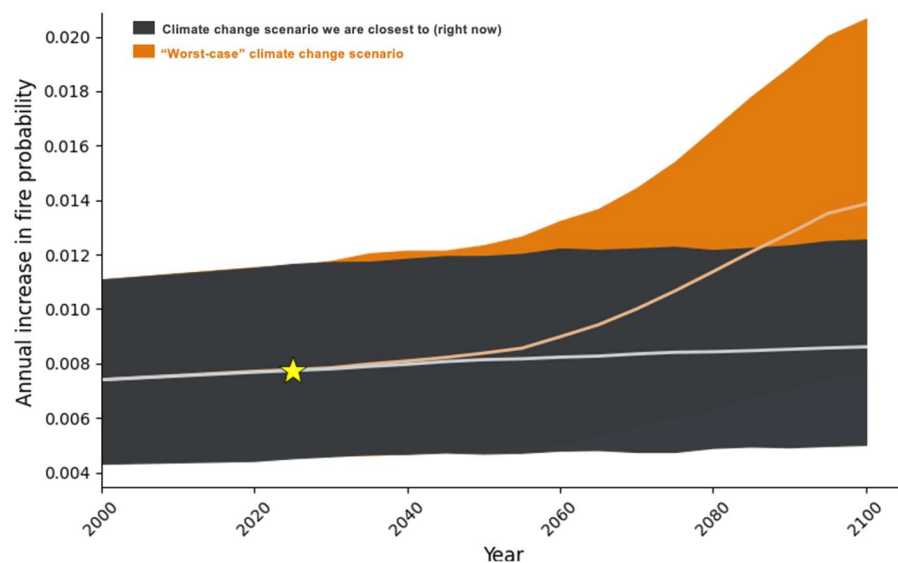


Figure 6. Historical and projected exposure to fire driven by climate change for Amazon basin projects. Detectable climate-driven fire exposure emerges after 2040 under worst case scenarios, becoming a material factor for risk assessments. Source: CMIP6 climate model data, downscaled and bias-corrected, proprietary processing via Jupiter Intelligence. Solid lines indicate the mean response, shaded areas show the 5–95 percent confidence interval, and the star marks the year 2025.

Understanding risks and how they evolve under climate change, such as increasing fire frequency, enables project developers to implement targeted mitigation and preparedness measures, for example, adjusting planting density in new afforestation projects or installing firebreaks in existing ones.

In-kind insurers such as CarbonPool address these risks by covering carbon losses from climate-driven fire events and **providing replacement credits to maintain project permanence.**

Comparison with recent studies

Our analysis provides **project-level insights for the Amazon basin using higher-resolution biomass and hazard exposure data**. Leveraging Chloris biomass data, detailed fire and drought mapping, and inclusion of lagged drought effects, this study delivers a regionally focused attribution analysis for Amazon REDD+, IFM, and afforestation projects.

These findings align with recent Chloris analysis², which indicate that **degradation has overtaken deforestation as the dominant threat**. Our findings also generally align with recent work by WRI and DeepMind³ which assessed global biomass drivers at 1 km resolution.

Conclusions

Understanding key drivers of risks **strengthens overall resilience of carbon markets**: It supports targeted mitigation strategies such as firebreak construction or species selection.

From an insurance perspective, **attribution analysis enables accurate pricing and efficient underwriting**, lowering costs for well-managed projects.

In addition, robust **digital MRV based on high resolution biomass data** have the potential for unlocking broader insurability (e.g., considering verification of claims due to digital MRV) and strengthening overall market confidence.

² Chloris analysis: <https://www.chloris.earth/new-findings-support-increased-finance-for-indigenous-land-stewardship>

³ Sims et al. 2025: <https://iopscience.iop.org/article/10.1088/1748-9326/add606>

