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Complementary Perspectives and Metrics Are Essential to End Deforestation

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ABSTRACT

Recent public and private policies seek to end deforestation by regulating the production and trade of forest-risk commodities. The design, implementation, and evaluation of these policies rely on metrics that are typically bounded in scope by either territories or supply chains, and therefore only provide a partial account of deforestation on the ground. We argue that metrics linking deforestation and forest degradation to commodity production need to consider two distinct questions: (1) How much of today's commodity production is associated with past deforestation? and (2) to what extent is today's deforestation driven by the prospects of producing a specific commodity in the future? This paper describes how metrics can respond to these questions by being classified according to their commodity or deforestation focus. We propose common terminology to facilitate the communication and use of these perspectives and metrics. We then make the case for combining perspectives through the monitoring and reporting of multiple metrics by governments, companies, and non-governmental organizations alike to both assess progress and drive more coordinated action to reduce deforestation.

1 | Introduction

More than 90% of tropical deforestation, totaling some 6.4–8.8 Mha year^{-1}, is driven directly or indirectly by agriculture, with beef, palm oil, and soy being linked to the majority of the conversion of forests to agricultural land (Pendrill et al. 2022). Commodity-driven deforestation and forest degradation have led to profound global impacts on the climate, biodiversity, and livelihoods. The associated commodities are either consumed domestically or exported, mostly to places in which deforestation for agricultural expansion has decreased or halted, allowing importing countries to outsource their environmental impact (Meyfroidt et al. 2010). In response, public and private policy initiatives are emerging to tackle deforestation in producing countries, such as the Glasgow Leaders Declaration on Forests and Land use at COP26 (UK COP26 2021), strategies to move towards deforestation-free supply chains in France (Ministère de la Transition Écologique et Solidaire 2018) or Germany (Bundesministerium für Ernährung und Landwirtschaft 2010), or proposed supply-chain regulations in the EU (European

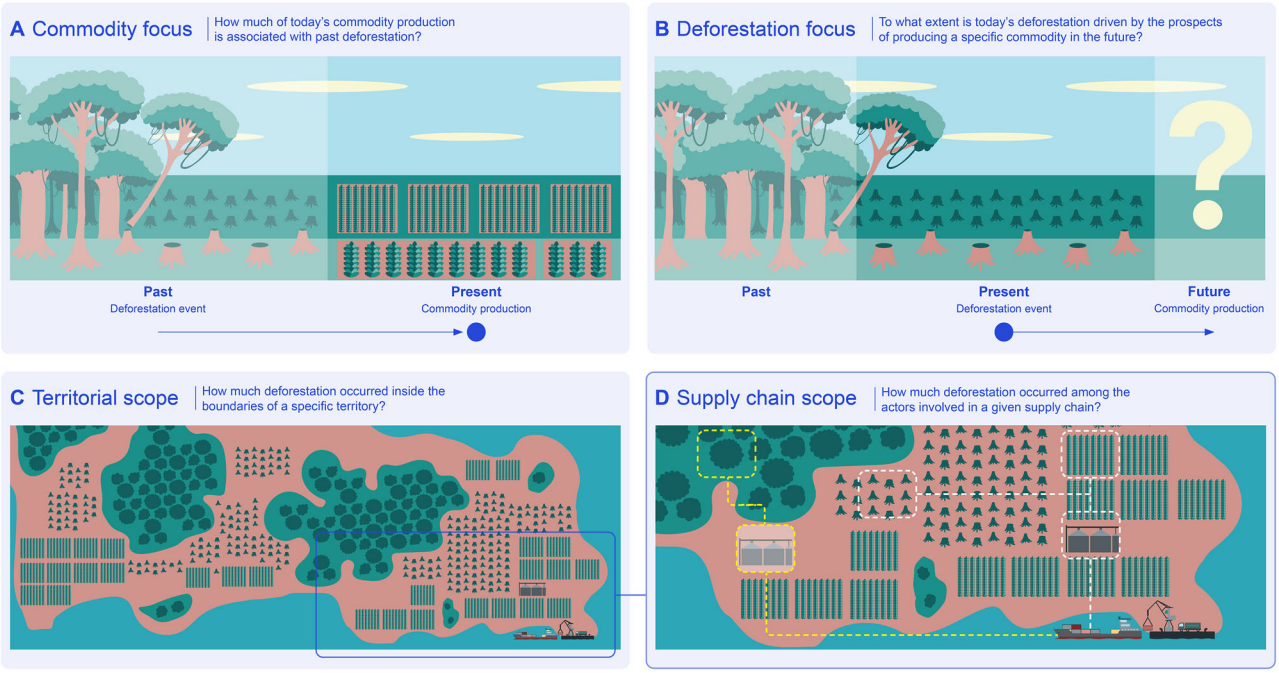

FIGURE 1 | Commodity (A) and deforestation (B) focus with territorial (C) and supply chain (D) scopes that can guide the use and development of deforestation metrics (including forest degradation).

Parliament and of the Council 2023), United Kingdom (UK Public General Acts 2022) and United States (Schatz 2021) (see Table S1). To date, zero-deforestation commitments have had a limited impact on global deforestation (Lambin and Furumo 2023). Understanding how to monitor and evaluate the links between deforestation and agricultural commodity production and consumption is critical for these initiatives to succeed.

Despite the increasing availability of data linking agricultural commodity production and supply chains to deforestation across the tropics, our ability to monitor the effectiveness of policies to reduce deforestation is beset by two significant challenges. First, deforestation policy measures are typically concerned about deforestation occurring within the bounds of either territories or supply chains (the "scope"; see Figure 1). As a result, regulation, enforcement, and monitoring efforts are necessarily limited to a portion of the deforestation on the ground. For instance, producing countries that seek to enforce deforestation laws within their borders often do not address the role of buyers and consumers of the commodities that are driving the deforestation in their territories (or "geographies"). In contrast, deforestation policies targeting specific agricultural commodity supply chains only address part of the deforestation occurring in the territories that countries or companies are sourcing from. For instance, EU member states operating under the new EU Regulation on Deforestation-free Products (EUDR) (European Parliament and of the Council 2023) will regulate company supply chains to ensure that commodities (and derived products) placed on the EU's market are grown in plots that are deforestation-free, but without the policy requiring that deforestation linked to the whole commodity sector or territory be reduced. Individual companies will necessarily focus on their own supply chains to manage regulatory and reputational risks but also maintain competitive advantage in their business (Ponte 2020).

Second, the choice of data and metrics to guide the design, implementation, and evaluation of policies is confounded by a plethora of terms that can confuse policy deliberations (see examples in Table S2). The term "deforestation" itself can be represented by different datasets, forest definitions, and whether "degradation" is included or not (Pendrill et al. 2022). The term "deforestation risk" has been used to refer both to the risk of exposure to past deforestation that is "embedded[1]" in current production and trade of specific commodities (where the focus is on the commodity in question) and to the risk of future deforestation (where the focus is on new deforestation).

Previous studies have emphasized the continued need for a public–private policy mix that can reinforce both government and company zero-deforestation commitments, considering both territories and supply chains (Lambin et al. 2018; Garrett et al. 2019; Lambin and Furumo 2023). However, the narrow scope of data and monitoring tools provides limited support for the design, implementation, and evaluation of such comprehensive policy mixes. To overcome this challenge, we first propose building common terminology and understanding about the type of information provided by existing metrics and the perspective that underpins them. Then, we use this framework to highlight the benefits and limitations of different metrics, and map a way forward to improve the design and evaluation of zero-deforestation commitments.

We conclude that deforestation reduction measures should be informed by a combination of metrics that (1) have both a territorial and supply chain scope and (2) are informed by assessments of past deforestation linked to commodity production (i.e., a "commodity focus") together with assessments of deforestation as it happens (i.e., a "deforestation focus"). Without such complementary perspectives, both territorial and supply

TABLE 1 | Proposed terminology and definitions for deforestation metrics according to their commodity or deforestation focus.

Evidence base	
Metric	***Description***
Territorial deforestation	Total area of deforestation occurring in a given region (property, jurisdiction, state, country, according to the study boundaries), regardless of subsequent land use
Commodity focus	
Metric	***Description***
Commodity deforestation or Deforestation footprint	Total area of past territorial deforestation associated with commodity production
as direct deforestation	The time between past territorial deforestation and commodity production represents the minimum time needed to prepare the land for production, or a cutoff date determined by a particular policy Timelines are short (e.g., 5 years for soybean or pasture in South America), or the time elapsed from a recent cutoff date (e.g., December 31, 2020, for the EU deforestation regulation (European Parliament and of the Council 2023))
as direct and indirect deforestation	Same as above, but the timelines are longer (several decades) and can include scenarios of "potential vegetation" Several land use change dynamics can be captured (e.g., transition from pasture to soybean) and may include amortization periods
Deforestation focus	
Metric	***Description***
Commodity-driven deforestation	Total area of territorial deforestation that is predicted to be turned into commodity production
with future deforestation	Deforestation events will happen in the future Metrics are based on land use change scenarios with high uncertainty Active area of research in land system science
with the latest deforestation	Deforestation events are the latest to have taken place, with no transition to commodity production yet Metrics are based on territorial deforestation and predictions of commodity production with lower uncertainty than the future deforestation timeline An underresearched area in land system science

chain initiatives are likely to fall short of their goals of reducing deforestation.

2 | Classifying Metrics for Deforestation Initiatives

The magnitude and trend in overall deforestation or forest degradation[2] within a given territory (or "territorial deforestation," see proposed terminology in Table 1) is the ultimate objective against which policy measures purporting to reduce deforestation and forest degradation should be evaluated. However, achieving this objective requires a set of distinct metrics to inform targeted interventions and progress. These metrics can be classified according to their "focus," that is, whether the metric relates to the production of a commodity or to a deforestation event, and according to whether the "scope" of the assessment is a territory or a supply chain (Figure 1).

A commodity focus is backward-looking, or retrospective, with metrics that seek to answer the question: "How much of today's commodity production is associated with past deforestation?" (Figure 1A). Deforestation can be attributed to production, considering the time typically needed to convert recently cleared land into productive use, which includes physically preparing the land, securing licenses and credit, and allowing the commodity to reach maturation. It is also possible to look much further back in time, for example, over several decades, and use amortization rates to allocate the responsibility for any connection between current or recent production and past deforestation, similar to what has been used for carbon emissions (Davis et al. 2014; Bhan et al. 2021). We propose that these metrics be described as "commodity deforestation" or "deforestation footprint" metrics (Table 1).

When the scope is a territory, these metrics convey a level of territorial "performance" based on the role of specific commodities in driving deforestation. When linked to supply chains, these metrics assign measures of commodity deforestation "exposure," sometimes called "risk" (Table S2), a term we propose should be used to communicate a level of associated responsibility to actors (e.g., traders, food producers, and financial institutions) connected to these supply chains. These metrics can be derived by the actors themselves, industry coalitions, civil society organizations, or governments. The level of "exposure" depends, in part, on the commodity traceability to territories of origin, which in itself

remains a challenge due to the complexity of supply chains, particularly for commodities with a large portion of indirect supply (zu Ermgassen et al. 2022) but also due to the technical capacity and investment made by companies (Lambin and Furumo 2023). For instance, Trase (2025) calculates deforestation "exposure" by assigning a share of deforestation from a given territory to traders and markets proportionally to the trade flows sourced from the territory. That is, for a jurisdiction producing 100,000 tonnes of a commodity for which 500 ha of forest was cleared, if a trader exported 50,000 tonnes from this jurisdiction, it is assigned 250 ha (i.e., 50%) of deforestation exposure (Trase 2022). Metrics with such a commodity focus could, in theory, be linked to any combination of past, current, and future deforestation (Table 1), but are typically limited to commodity production in the year(s) of interest and the past deforestation that was associated with this production. This, in turn, means that the monitoring and assessments of impacts, responsibilities, and performance at a given moment are limited to past action, rather than what is actually happening in that year. Since many of the primary drivers of deforestation take many years to reach maturity (e.g., cattle, palm oil, cocoa, coffee, rubber, and pulpwood), lags between deforestation actions and associated changes in commodity-focused metrics can be considerable.

In contrast, a deforestation focus is forward-looking, or prospective, with metrics that seek to answer the question: "To what extent is today's deforestation driven by the prospects of producing a specific commodity in the future?" Answering this question enables a stakeholder to interpret deforestation as being driven by the activities of that sector (Figure 1B). We propose that these metrics be described as "commodity-driven deforestation" (Table 1). Within a territory, producer governments may use these metrics to regulate or blacklist jurisdictions, enforce laws, or motivate sectors into making deforestation commitments, while some certification schemes sanction producers based on deforestation activity within certified properties (e.g., as in the RSPO New Planting Procedure, RSPO 2021). Making the link between ongoing deforestation and the expansion of specific commodities in the future (as purported drivers of that deforestation) represents an active area of research in land system science. For example, links can be established through forecasts based on recently observed land-use change trajectories using methods ranging from simple projections (Henderson et al. 2021) or statistical models (Mosciaro et al. 2022) to process-based economic or agent-based models (Dou et al. 2020; Villoria et al. 2022), or combinations thereof (Gollnow et al. 2018). Alternatively, the location of deforestation within concessions granted for specific production systems, or the spatial configuration of deforestation, may indicate the intended land-use. For instance, deforestation for industrial palm and pulp plantations often follows consistent spatial patterns such as grids or contour-like surfaces with networks of roads and canals (Gaveau et al. 2022). These features could be used to predict the intended land use before commodities come into production.

Beyond the above challenge, deriving the metrics that combine today's deforestation with a given commodity supply chain is challenging since production and trade have yet to take place. One possible approach is to link today's deforestation to the actions or investments of specific supply chain actors involved in a particular commodity sector or consider past supply chain configurations in the region where deforestation has occurred and their "stickiness" (Reis et al. 2020).

The Brazilian soy sector provides a useful illustration of the ways in which stakeholders apply metrics with differing focus and scope to evaluate deforestation. Soy is produced in the present time (Figure 1A) on land that was cleared in the past. The amount of deforestation assigned to the crop can be calculated within a territory (Figure 1C; e.g., to determine compliance with the Amazon Soy Moratorium, Soy Moratorium Portal 2025) or through the soy supply chain to specific actors (Figure 1D, as in Trase 2025). Deforestation in the present time (Figure 1B, tracked by the Brazilian government; TerraBrasilis 2025) might only see production 5 years into the future but can be assigned to soy based on historical or modeled land use dynamics in the territory (Figure 1C) and the soy supply chain based on current investment of actors in the region (Figure 1D; yellow dashed line linked to storage facility under construction). Deforestation metrics that combine a commodity focus (Figure 1A) and supply chain scope (Figure 1D) will allow actors to make supply chain decisions when soy is purchased and traded, while those with a deforestation focus (Figure 1B) and a territorial scope (Figure 1C) can inform actors on the performance of the sector as a whole in the territory. Bringing additional information from metrics that combine a deforestation focus (Figure 1B) and supply chain scope (Figure 1D) would also help prevent deforestation before it happens. Following the above terminology and classification, we then look at the limitations of existing metrics through to the perspectives that underpin them.

3 | The Limitations of Using a Single Focus and Scope

Following the above terminology and definitions, we note that deforestation metrics employed to monitor the progress of deforestation policies are too often limited to only one focus and scope, each of which has its own benefits and limitations (Table 2). This narrow view, in turn, can provide a misleading illusion of progress against deforestation.

In producing countries, the monitoring and enforcement of deforestation policies often rely on metrics that have a deforestation focus and a territorial scope, using recent or real-time deforestation data to inform the effectiveness of such policies. This approach, however, can be sensitive to the scale of analysis (zu Ermgassen et al. 2024) and limited by the lack of connection between deforestation, commodity production, and supply chain actors. Policies relying upon these metrics risk addressing deforestation events only after they have happened and may only lead to temporary reductions and/or leakage of impacts to other regions (Table 2). This territorial information should be complemented by a supply chain scope that highlights actors who are set to benefit from future production on the newly cleared land. Deriving such metrics requires predicting not just deforestation, but the spatially explicit nature of infrastructure investments and expansion of specific commodities on newly deforested land, as well as the links to downstream supply chain actors. These actors may be individuals or companies, those that store or transform production and maintain an enduring connection to a region through their supply shed (e.g. silo, mill,

TABLE 2 | Description of deforestation metrics according to their territorial or supply chain scope and commodity or deforestation focus. (See Table S2 for classification of metrics from specific guidance, policies, and initiatives.)

Scope	Territory	Supply Chain
Focus		
Commodity (retrospective) "Commodity deforestation" or "deforestation footprint" metrics	*Primary concern*	
	Commodities produced in a territory (farm, jurisdiction) and its deforestation history	Commodities sourced by a given supply chain and their deforestation history
	Benefits	
	Places the commodity deforestation within a wider jurisdictional performance	Uses data on actual commodity flows, providing direct linkages between downstream suppliers and deforestation
	Risks	
	Governance responses cannot be proactive as focused on historical rather than new deforestation	Encourages cleaning supply chains rather than addressing territorial deforestation overall
	Examples	
	Determining the risk of non-compliance in the EU deforestation regulation (European Parliament and of the Council 2023) based on a country or region's deforestation history	Due diligence on the import of forest-risk commodities, for example, the French platform for the Statégie Nationale de lutte contre la Déforestation Importée (Ministère de la Transition Ecologique 2023)
Deforestation (prospective) "Commodity-driven deforestation" metrics	*Primary concern*	
	Deforestation in one or more territories (e.g. farm, jurisdiction), which may lead to the production of one or more commodities in the future	Current deforestation that can be linked with the future supply chain of an actor (e.g., via infrastructure investments)
	Benefits	
	Focus on deforestation as it happens, and can confirm a genuinely "deforestation-free" status for properties or jurisdictions	Allows for a risk assessment prior to sourcing the commodity or making an investment in infrastructure
	Risks	
	Link to commodity production may be only hypothetical	The general lack of available tools and metrics for decision making and the link to supply chain remains partly hypothetical due to the lag between deforestation and commodity production
	Examples	
	Certification schemes that prohibit new deforestation on properties, and cases where properties or jurisdictions can be blacklisted due to deforestation	Proforest's soy risk analysis (Proforest n.d.) considers future production or schemes that trigger grievances to property owners

slaughterhouse), domestic and international traders (exporters, importers) that own or are investing in facilities and have contracts in the regions, the banks and financial institutions that provide loans, or consumers and consumer governments (e.g., EU member states) that are historically linked to the region. Present and future commodity sourcing, as well as investments and infrastructure planning, can already benefit from some tools, such as the ProForest soy risk analysis tool (Proforest n.d.) (Table S2), and should also include land use forecasting to help governments and traders curb deforestation before it happens.

In contrast, consumer governments and companies are typically concerned first and foremost with cleaning up their supply chains through metrics with a commodity focus and a supply chain scope (e.g., French platform for the Stratégie Nationale de lutte contre la Déforestation Importée; Ministère de la Transition Ecologique 2023, or Soft Commodities Focus Municipalities; Soft Commodities Forum 2022; Table S2). Some initiatives may also employ a territorial scope for the purposes of benchmarking the risk of deforestation associated with commodity sectors (e.g., EUDR) or certifying products, but trends in territorial deforestation remain separate from the monitoring and reporting of supply

chain performance. For instance, each Amsterdam Declarations Partnership country has to report progress through the amount of certified product imported (i.e., import volume of Round Table on Responsible Soy RTRS-certified soybean) (Amsterdam Declarations Partnership 2020), which is different from the information used to assign soy certification through territorial requirements (RTRS 2020). By recognizing these differences among metrics, actors from all sectors will be better equipped to propose a set of metrics that, when combined, can prevent different actors from only looking at a portion of territorial deforestation.

4 | Combining Metrics to Unlock More Comprehensive Policies

Unlike other environmental impacts, such as water or air quality, the irreversible nature of deforestation and the time lag between deforestation and commodity production make the design, implementation, and evaluation of measures more challenging. Combining metrics with both a commodity and deforestation focus, as well as a territorial and a supply chain scope (Table 2), can help enable and catalyze a much-needed integration of public and private deforestation policies. This means monitoring deforestation as well as the roles and responsibilities of actors, including consumers and investors.

We see key stakeholders playing the role of knowledge hubs or information brokers, for example, civil society organizations, non-governmental organizations, or multistakeholder partnerships taking a leading role in combining metrics, provided the information on progress is communicated transparently, especially by private actors. Producer and consumer governments can also play an active role by collaborating to align on data inputs to ensure better overlap of information on both territorial and supply chain performances, notwithstanding the challenges in coordinating policy measures across multiple countries, actors, and regions.

Our review of existing tools and initiatives (Table S2), while far from comprehensive, reveals that such a combination rarely exists, especially in the design of a single policy. To ensure that supply chain deforestation policies are actually reducing deforestation, monitoring needs to include metrics that go beyond a purely supply chain scope and also evaluate the performance of the commodity sectors in question across entire producing regions (e.g., see Accountability Framework initiative; Accountability Framework Initiative 2024; Table S2), together with additional policy instruments from producer governments and industry coalitions (e.g., fines, legal action, moratoria, payment for ecosystem services). On the other hand, deforestation policies in producing regions could also be complemented by information on supply chain actors (e.g., facilities owned in the region) who are often directly or indirectly responsible for the deforestation occurring in the first place. Not including such information can place additional burdens on producers, as responsible alone for fixing the deforestation problem, leading to barriers to enter markets and a risk of excluding smallholders (Ponte 2020).

As a way forward, we suggest that initiatives be explicit about the focus and scope that define the metrics being used for monitoring and reporting. A simple mapping of metrics according to our proposed terminology (Table 1) should help highlight certain blind spots in overall performance and identify the additional and complementary metrics needed for monitoring. This aim reveals a set of critical research priorities. First, research should strive to produce multiyear data and metrics describing spatially explicit deforestation-to-commodity transition time series, as well as the mapping of sourcing areas for both direct and indirect suppliers (zu Ermgassen et al. 2022). Second, civil society organizations and multistakeholder groups should continue to strive for more transparent commodity supply chain information to allow for more metrics and perspectives to be combined in independent monitoring efforts. Finally, future research should focus on links between current deforestation and future supply chains as a way to inform decisions that ensure that deforestation is curbed before it happens.

5 | Conclusion

Reducing agriculture-driven deforestation is an essential and urgent part of global efforts to mitigate climate change and prevent further biodiversity loss. Tackling deforestation effectively requires addressing the drivers of deforestation while avoiding blind spots in measuring performance and progress across actors, sectors, and regions. Our proposed classification of deforestation metrics into a commodity or deforestation focus and a territorial or supply chain scope can prevent such blind spots in monitoring. In particular, metrics with complementary perspectives can provide a clear measure of progress and help ensure that policies to end deforestation are more effective.

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Ethics Statement

No ethics approval was required for this work.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data are available in the main text and the Supporting Information.

Endnotes

[1] Varyingly termed "embedded deforestation", "embedded land use change", "embodied deforestation", "associated deforestation", "imported deforestation", or "deforestation footprint" (see examples in Table S2).

[2] While we only mention "deforestation" in the remaining text, the argument is described considering "deforestation and forest degradation."

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary Material: conl13145-sup-0001-SuppMatt.pdf