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Understanding deforestation lock-in: Insights from Land Reform settlements in the Brazilian Amazon

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Cropland and pasture expansion continues to erase natural ecosystems at a staggering speed globally, notably in the tropics. Conventional policy approaches, usually focused on a particular land-use change driver (e.g., specific commodities) or individual regulations (e.g., the Amazon Soy Moratorium), have consistently failed to achieve sufficient or sustained results. The swift reversal of Brazil's earlier success in reducing Amazon deforestation – now again accelerated – offers perhaps the most sobering illustration of that. Therefore, this article draws from scholarship on sustainability transitions to propose a more comprehensive systems view of unsustainable land-use patterns. We examine persistent tropical deforestation as a case of "lock-in," using a transitions lens, and explore its constitutive elements. As a case study, we analyze the situation of Land Reform settlements in the Brazilian Amazon, where as much as one-third of that biome's deforestation takes place. While subject to some specific factors, those places are also enmeshed in a broader setting that is common across the Brazilian Amazon's deforestation frontier (e.g., infrastructure conditions, market demands, and sociocultural norms). Drawing from document analysis of Brazilian policies and fieldwork in three Land Reform settlements in Pará State, we expose multiple forms of techno-economic, institutional, and socio-cognitive lock-in that together drive deforestation systemically in those settlements. These drivers form a strongly consolidated socio-technical regime around large-scale agriculture that includes material and immaterial factors (e.g., cultural ones), a regime that not only resists change but also – like a vortex – pulls others into it. Escaping deforestation lock-in may thus require outside forces to help local actors destabilize and eventually replace this unsustainable land-use regime. International zero-deforestation efforts offer a starting point, but a transition requires moving beyond piecemeal, incremental change or end-of-pipe approaches and toward concerted, strategic action

that addresses multiple of those regime elements in a coordinated way to replace it as a system. We argue that understanding deforestation lock-in is vital for tackling its worrisome persistence and that sustainability transitions theory offers an illuminating, but still underutilized, framework to analyze and eventually overcome unsustainable land use.

KEYWORDS

smallholders, tropical deforestation, land-use change, sustainability transitions, forest conservation, environmental governance, family farming, transformative change

Introduction

Tropical deforestation has been a major consequence of unsustainable development in recent decades. Despite occasional success stories in countering it, the global trend remains grim. Over 5 million hectares (Mha) of tropical forests are lost each year to expanding commercial agriculture alone (Pendrill et al., 2019). In South America, between 1985 and 2018, as many as 268 Mha of natural ecosystems were cleared to make way for either cropland or pastures (Zalles et al., 2021). Agriculture drives as much as 90-99% of all tropical deforestation worldwide (Pendrill et al., 2022). Such an agricultural expansion meets growing global demand for commodities without necessarily bringing about local development; at times, it drives maldevelopment, with further wealth concentration and social exclusion (Russo Lopes et al., 2021). From an environmental standpoint, too, deforestation often represents tropical countries' most significant plight. Land-use change emissions in Brazil, for example, account for nearly half of the country's total and twice as much as those stemming from energy use (SEEG, 2020).

Emerging talk of supply-chain sustainability and commodity traders' nominal zero-deforestation commitments have not prevented tropical deforestation from continuing to be an outcome of unsustainable agri-food systems (see Zu Ermgassen et al., 2020a,b).[1] In the Amazon's case, analysts and decision-makers generally acknowledge multiple deforestation drivers such as inadequate land tenure, weak law enforcement, unfettered expansion of roads and other infrastructure, and growing market demand for forest-risk commodities (Margulis, 2004; Moran, 2016; Fearnside, 2018; Coelho-Junior et al., 2022). However, while those multiple issues are acknowledged, they are most often assessed as individual drivers rather than a coherent and self-reinforcing system that results, among other things, in deforestation.

A sustainability transitions lens instead allows us to assess persistent deforestation as a harmful effect of a dominant land-use regime in need of change. In his seminal work about the existence of a "carbon lock-in" in fossil-based energy systems, Unruh (2000, p. 827) noted that "lock-in implies that there are systematic forces that make it difficult to change the development path." Such a view requires acknowledging various structural path dependencies – technical, economic, institutional, political, and cultural (see Seto et al., 2016; Janipour et al., 2020; Trencher et al., 2020). In the case of land use, it may be possible to speak of an analogous "deforestation lock-in." Sustainability transitions frameworks have been increasingly applied to environmental fields such as energy (Geels et al., 2017a; Rogge et al., 2017), agri-food systems (El Bilali, 2019), and the bioeconomy (Gawel et al., 2019). In the realm of forests, the concept of lock-in and transitions scholarship have only recently started to receive attention as a lens for analyzing land-use change (see Delabre et al., 2020; Furumo and Lambin, 2021).

We identify at least three reasons why transitions theory can help answer the growing calls for more systems thinking on tropical deforestation (see Arias-Gaviria et al., 2021). First, a sustainability transitions lens does not try to single out key drivers (e.g., soy or oil palm expansion) as if they resulted purely from a market demand to be made more environmentally stringent. Instead, it regards various elements cohering into a complex web of material and immaterial structural factors (e.g., institutions, technologies, markets, infrastructure, and culture) that jointly result in deforestation. Second, it conceptually recognizes that dominant practices are by default resistant to change and, therefore, unlikely to yield to casual, un-strategic, or erratic interventions that do not regard the whole. Third, as a comprehensive multi-level framework, a sustainability transitions lens allows analyses to account for global trends as much as for mid-range factors or case-specific characteristics that sometimes escape assessments focused either

1 We acknowledge that the debate around zero-deforestation commitments encompasses other types of natural ecosystems. In this paper, we use the term "deforestation" to refer also to such other forms of ecosystem conversion.

on single government policies (e.g., Brazil's Forest Code) or on demand-side supply chain interventions (e.g., the Amazon Soy Moratorium), sometimes offered as a panacea.

This article first puts forth the concept of deforestation lock-in by elaborating on transitions theory in relation to land-use change and then applies it to the case of Land Reform settlements in the Brazilian Amazon. Most analyses of such settlements have focused either on the role of social movements (Wolford, 2010), land concentration (Navarro, 2009; Sparovek and Maule, 2009), neoliberal redistributive policies (Wolford, 2007; Rosset, 2009), agrarian struggles and violent conflict (Alston et al., 1999; Alston and Mueller, 2010), land grabbing (White et al., 2013), gender issues (Razavi, 2003), or the impacts of the COVID-19 pandemic on rural development (DeVore, 2021; see also Russo Lopes and Bastos Lima, 2020). Yet, those settlements are also critical to land-use change, for they cover a substantial area of the Amazonian territory. About one-third of all deforestation in the Brazilian Amazon happens in these Land Reform settlements (though not necessarily by legitimate settlers, as we shall see) (Alencar et al., 2016; Pereira et al., 2022). To fill that gap, we draw insights from fieldwork in three settlements in Pará State, in the eastern Amazon, linking local stakeholder perspectives to broader land-use change dynamics in the region. We expose how local actors become constrained to adopt environmentally degrading behaviors even when they actively seek more sustainable alternatives, and discuss levers that may exist for transformative change.

Tropical deforestation viewed through the lens of sustainability transitions

Persistent issues, systemic issues?

Growing global concerns about tropical forest loss are yet to translate into effective and enduring strategies to counter it. To date, most efforts have arguably been piecemeal and insufficiently comprehensive, leaving unchecked a myriad of environmental and social issues (IPBES, 2019; IPCC, 2019). In the Amazon's case, a looming tipping point may start an ecological dieback process that can transform much of the rainforest into a dry savanna, with significant consequences for its ecosystem services and impacts both in South America and worldwide (Lovejoy and Nobre, 2018; Bastos Lima et al., 2021).

Efforts to counter Amazonian deforestation have tended to focus on one of two elements. On the one hand, there has been attention to command-and-control policies that can suppress degrading land-use practices – but which can also be easily suspended by a change of government, as Brazil's case soberly demonstrates (West and Fearnside, 2021). On the other hand, there has been a groundswell of demand-side measures such as mandatory due diligence or voluntary commodity-trader sourcing policies (Gardner et al., 2019; Zu Ermgassen et al., 2020a; Schilling-Vacaflor and Lenschow, 2021). However, such initiatives often emphasize the political priorities of consumer countries and give little consideration to the specific institutional settings of producing regions (Bastos Lima and Persson, 2020). Moreover, they seldom pay attention to alternative development pathways beyond the sector they have vested interests in maintaining. They often seek to improve law enforcement, particularly around ecosystem conversion, but they are yet to account for the complexities of commodity production (e.g., widespread indirect sourcing; see Zu Ermgassen et al., 2022), broader socioeconomic issues (Gustafsson and Schilling-Vacaflor, 2022; Sellare et al., 2022) or the transformative change put forward by local initiatives led by smallholders and traditional populations (see Brondizio et al., 2021). As such, they risk cleaning deforestation out of specific supply chains without addressing the issues of unsustainable development on the ground (Mammadova et al., 2022). Critical underlying deforestation drivers such as systemic social, cultural, or other institutional factors frequently remain overlooked in such conventional approaches (Le Polain de Waroux et al., 2021).

Considering this complexity, we posit that sustainability transitions are a valuable lens with which to examine – and potentially address – tropical deforestation more strategically. Its scholarship has been substantially developed over the past decades assessing societal change toward renewable energy, and it has been increasingly applied also to other areas such as agri-food systems (see El Bilali, 2019). Yet it remains new to land-use sustainability debates. A transitions lens would regard the dominant development pathway in the Amazon as a *socio-technical regime*, understood as "the interlinked mix of technologies, infrastructures, organizations, markets, regulations, and user practices" forming systems that "have developed over many decades, [and where] the alignment and coevolution of their elements make them resistant to change" (Geels et al., 2017b, p. 1,242). Transitions theory would therefore regard the elusive nature – and failure – of most efforts to tackle deforestation not as owing only to their own individual limitations, or as ineffective just due to their inadequate policy design. Instead, the transition lens suggests that those failures all stem from the internal coherence of the present land-use regime and its consequent resistance to change. Moreover, as many initiatives come from actors who are *status quo* beneficiaries, they are inherently limited and hardly challenge the stability of current practices, regardless of how harmful they are to others.

Understanding lock-in dynamics

Lock-in has long been advanced as a concept in economics, energy studies, and the sustainability transitions literature (Unruh, 2000; Seto et al., 2016; Wesseling and Van der Vooren, 2017; Janipour et al., 2020; Trencher et al., 2020). Its first

feature has to do with the increasing returns of established practices. Drawing from earlier scholarship on path dependency and examining the carbon lock-in of fossil-based energy, Unruh (2000) identified four classes of increasing returns that constitute systemic factors making dominant practices resistant to change. They relate to increasing economies of scale, learning economies, adapted market expectations, and network economies (see also Janipour et al., 2020). Economies of scale relate to decreasing per-unit costs as fixed costs spread over growing production (Mansfield, 1988). In the case of industrial farming, one can think of grain silos, dedicated transport infrastructure, or meatpacking facilities as elements that, once in place, reduce per-unit costs. Learning economies refer to the development of skills, specialized knowledge, as well as cognitive routines that increase efficiency (Arrow, 1962; Nelson and Winter, 1982). In the Amazon, that translates as highly technified agricultural commodity production and the (cognitive) consolidation of "agribusiness as we know it" as a social fact (see Hoelle, 2015; Santos et al., 2019). Adapted market expectations have to do with growing integration and tuning between, on the one hand, what producers have to offer, and on the other hand, what consumers, the wider economic structure, or the broad public demand. Finally, network economies refer to the advantages that stem from increased inter-industry coordination (e.g., supply-chain relations, the creation of private associations), established relationships with finance, as much as links to government agencies and educational institutions. These factors represent "cohesive forces" that create, coordinate, and perpetuate "the knowledge, skills and resources needed to maintain a technological system" (Unruh, 2000, p. 822). **Table 1** presents these classes of increasing returns with examples from dominant land uses in the Brazilian Amazon and some key references.

In the Amazon case, such dynamics are critical for understanding the increasing prowess of persistent deforestation drivers such as soy cultivation and cattle ranching. These are highly oligopolistic agroindustrial complexes that involve networks of indirect sourcing but are led by large-scale farmers and a handful of commodity traders (Wesz, 2016; Zu Ermgassen et al., 2022). Those agribusiness players have become increasingly powerful in Brazil, both economically and politically (Kroger, 2017; Sauer, 2019; Bastos Lima, 2021), as part of a wider global network of consumers, financiers, and seed or agrochemical input providers (Medina, 2022). Their growing power, in turn, creates a snowball effect that secures economic gains and further consolidates their dominant position. The literature has long shown that retained earnings and core companies' internal cash flow often are principal sources of investment that reinforce their dominance (Henwood, 1998). As Unruh (2000, p. 823) puts it, the profit that companies make "logically goes toward strengthening their dominant design-based core competencies," in a "continued re-investment of returns [which] creates a self-reinforcing positive feedback that can lock-in existing technological solutions. Likewise, when capital is sought from outside, financial institutions can further reinforce lock-in through risk-averse lending practices."

In the case of agriculture, patented genetically-modified seeds and chemical inputs have formed a prevalent technological arrangement associated with expanding industrial monocultures such as soy (McMichael, 2009; Clapp, 2018; Giraudo, 2020). More recently, leading agroindustries have also become increasingly active in finance, in what Clapp et al. (2017) have termed the "financialization" of agriculture. Commodity traders, for example, have become major financiers of soy farming while also profiting from price speculation and grain-market volatility (Salerno, 2017). Core companies thereby have not only strengthened their dominance but also promoted the growth of such industrial agri-food systems that result, among others, in agricultural expansion over tropical ecosystems (McMichael, 2012; Clapp, 2021; Pendrill et al., 2022). Akin to greenhouse gas emissions in the case of fossil-based energy, deforestation arises as a noxious product of the system.

Yet, it is important to look beyond techno-economic dynamics and to the broader social, political and cultural embeddedness of such system. Agroindustry groups such as Brazil's soy-growers association (Aprosoja) or the Brazilian Association of Vegetable Oil Industries (ABIOVE) have not only represented formidable political lobbies (Kroger, 2017), but they have also become increasingly relevant governance actors, negotiating voluntary land-use rules and possible compensations for conservation with like-minded environmental NGOs (Bastos Lima and Persson, 2020). Typically, the activities of such private-sector associations come to "merge with the interests of the oligopolistic dominant design producers as their common reliance on the continued expansion of the technological system becomes mutually obvious" (Unruh, 2000, p. 824; see also Galbraith, 1967). These private interests also blend with key governmental agencies, which become increasingly oriented toward providing for sectoral needs. State and private sector become enmeshed in a common language, routine practices that are not questioned, and the "revolving door" whereby the same people from key industries take up appointed positions in government and vice-versa (Unruh, 2000; Meghani and Kuzma, 2011). The result sometimes is regulatory capture, when public policies end up being shaped to serve vested sectoral interests instead of society at large (Lowi, 1979; Dal Bó, 2006).

Finally, other auxiliary institutions also play key roles. For one, universities have long been important players in promoting input-intensive, "green revolution" agriculture in places such as the US and Brazil (Nehring, 2022). Ever more developed relationships between agribusiness and higher learning institutions have had a practical impact (e.g., agronomic R&D) as much as a wider cultural and cognitive one (see Campbell and Dixon, 2009). That is because of disciplines

and disciplining that "are often the source of 'rules of thumb' that are ultimately applied routinely" by "a large, self-sustaining network of like-minded professionals and institutions that are invaluable to the growth of the system" (Unruh, 2000, p. 823). As Unruh (2000, p. 828) elaborates,

> "Even new entrants to the job market find incentives to conform to the existing [socio-technical regime]. Rather than subjecting themselves to the risk of an uncertain career with a new technological alternative, trainees may prefer to prepare for positions in which demonstrated opportunities exist. These 'preferences' are not autonomous but evolve in a path-dependent manner with [socio-technical regime] expansion."

That then shapes the provision of public services such as rural extension (see Bragança et al., 2022), or credit lines, as well as broader socio-cultural attitudes and expectations (see Le Polain de Waroux et al., 2021). For instance, favorable journalism and media have actively contributed to creating an "automobile culture" that became part of the carbon lock-in (Fink, 1988; Unruh, 2000). Likewise, in places such as Brazil, agribusiness has long shaped supportive public attitudes to obtain societal legitimacy and a social license to operate, such as through "feeding the world" narratives or self-branding as national economic champions (Bastos Lima, 2021). That, in turn, has fostered an analogous "deforestation culture" around the continuous expansion of land-use change practices in the rural Amazon (see Hoelle, 2015; Santos et al., 2019). More broadly, social buy-in and favorable social attitudes have shielded deforestation-driving agricultural sectors (e.g., cattle ranching) from environmental critiques or links to climate change in Brazil, for example (Lahsen, 2017; Bastos Lima, 2021). Such public attitudes facilitate broad political support that strengthens agribusiness' grip on public regulations, in a self-reinforcing cycle that reproduces the current socio-technical regime. Unruh (2000, p. 826) notes that "these techno-institutional infrastructures create persistent incentive structures that strongly influence system evolution and stability," which "in advanced stages [. . .] can become the locus of lock-in."

That arguably has been the case with soy in Brazil, the country's most cultivated crop and a major deforestation driver (Rausch et al., 2019). Over the past decades, soy has become a fast-expanding globally traded commodity and the world's animal feed protein of choice (Song et al., 2021). Infrastructure for grain storage, land transporting, and shipping has been booming in sensitive regions such as the Amazon (Sauer, 2018). Brazilian domestic industries that rely on soy (e.g., poultry and pork) have also grown, alongside the grain's increasing utilization for biodiesel (Caro et al., 2018; Bastos Lima, 2021). Meanwhile, foreign markets (initially Europe and Japan, and

TABLE 1 Classes of increasing returns that foster lock-in.

	Logic	Examples in the case of Amazon land use	References
Economies of scale	Costs decline and business becomes more efficient (and, thus, profitable) as fixed costs are spread over an increasing volume of production.	Investments from meatpacking conglomerates in slaughterhouses or cattle-supply monitoring mechanisms; soy-trader operational costs and investments in silos, private ports, grain terminals, other shipping or rail-transport infrastructure.	Mansfield, 1988; Fearnside, 2007; Van Dijck, 2013.
Learning economies	The accumulation of knowledge and specialized skills tends to improve performance and reduce costs over time. Learning also results in increasingly established cognitive routines.	How to cultivate soy (originally a temperate climate crop) in tropical soils; increased productivity from cattle-ranching; the "deforestation culture" that shapes cognitive preferences and environmental behaviors; the know-how for sourcing and trading cattle in a region with poor infrastructure.	Arrow, 1962; Nelson and Winter, 1982; Hoelle, 2015; Santos et al., 2019.
Adapted expectations	Progressive reduction of uncertainties. Market players become increasingly used to and confident about the performance and reliability of a given production sector. User or buyer preferences and habitual routines become increasingly adapted, facilitating market expansion and the reduction of transaction costs.	The expansion of poultry or pork factory farming relying on soybean feed; Brazil's growing blending mandates for biodiesel based on soy oil or beef tallow; banks, credit-lenders and other financiers' grown confidence about soy cultivation in Brazil's tropical areas.	Arthur, 1991; Giraudo, 2020; Bastos Lima, 2021.
Network economies	Interrelations develop and give rise to increasing coordination between businesses (e.g., direct or indirect suppliers), with finance, government agencies, and between producers and knowledge institutions.	The formation of strong agribusiness associations that secure political representation (e.g., Brazil's rural caucus) and offer services to soybean growers (e.g., Aprosoja and ABIOVE); established finance flows; key links between private agroindustry and public institutions (e.g., Embrapa) as well as universities doing agronomic research that enables and improves soy production.	Unruh, 2000; Sauer, 2019; Nehring, 2022.

Source: Adapted from Unruh (2000).

later emerging Asian markets such as China and Thailand) have also developed supply-chain relationships of increasing reliance on Brazilian soy (Oliveira, 2019). As the sector grows, becomes richer and more politically preeminent, its influence on public policies increases concurrently (Sauer, 2019); more infrastructure for greater or easier soy production and exporting comes into place (Fearnside, 2007); and soy thus becomes a bigger business, more efficient and with greater sunk capital invested, both public and private.

This positive feedback cycle continues, and the lock-in solidifies. The various elements support one another, and some can harden their resistance to change if another becomes weakened (Seto et al., 2016). For instance, in the face of perceived regulatory or divestment threats from abroad, socio-cognitive coalescing around large agribusiness has strengthened in Brazil, where the sector is now commonly dressed as "patriotic" and framed in terms of a nationalistic resistance against foreign interference (Bastos Lima, 2021). Deforestation then emerges as just an unfortunate externality – perhaps a necessary cost. In such a context, "[t]he difficulties governments have in removing outdated, even counterproductive, subsidy programs can equally be seen as a symptom of [. . .] lock-in" (Unruh, 2000, pp. 827, 828). Such subsidies become enmeshed in policy mixes that get updated but still build upon such old – and often harmful – elements. That is notoriously exemplified by the Kandir Law, a total tax exemption on raw-grain exports that Brazil introduced in 1996 when, after a change of the national currency, the country was in dire need of foreign exchange. Despite the multiple and sustained economic drawbacks, this outdated incentive has become nigh politically impossible to remove (Varsano, 2013; Dias da Silva and Mello Gonçalves, 2019).

An unsustainable land use "momentum"

Hughes (1983) argues that those kinds of positive feedback loops create "momentum" for a system, making it increasingly hard to change. He provides a detailed description of this process, using an analogy from mechanics to explain the inertia the system acquires,

> "As a system grows, it acquires momentum. [. . .]. A system with substantial momentum has mass, velocity, and direction. [T]he mass consists of machines, devices, structures, and other physical artifacts in which considerable capital has been invested. The momentum also arises from the involvement of persons whose professional skills are particularly applicable to the system. Business concerns, government agencies, professional societies, educational institutions, and other organizations that shape and are shaped by the technical core of the system also add to the momentum. Taken together, the organizations involved in the system can be spoken of as *the system's culture*. A system with such mass usually has a perceptible rate of growth or velocity. Often the rate accelerates. A system usually has a direction, or goals. The definition of goals is more important for a young system than for an old one, in which momentum provides an inertia of directed motion." (Hughes, 1983, p. 15, italics added).

Later we will elaborate on the "goals" or "direction" that have characterized Brazil's agricultural expansion into the Amazon and other biomes. For now, it is worth noting that the recognition of environmental problems (and their economic consequences) associated with tropical deforestation emerged belatedly, akin to what happened to greenhouse gas emissions once the fossil-based energy system was already in place. Not only does lock-in slow or prevent the emergence of alternatives, but it also sustains an inertia that "exhibits itself as market and policy failures that go systematically uncorrected or even exacerbated by institutional forces" (Unruh, 2000, p. 826). This phenomenon has been characteristic of Brazil's agricultural expansion, as the conventional land-use system resists change despite the increasingly clear environmental issues associated with vegetation clearing and economic losses even for soy producers themselves (see Flach et al., 2021; Leite-Filho et al., 2021).

Change becomes hard not because of mindless inertia in a literal sense but because of politics, the power of regime incumbents, and economic as well as cognitive or socio-cultural constraints (Geels, 2014; Avelino, 2017). Dominant actors may pursue incremental improvements along path-dependent trajectories, but those usually are insufficient to address sustainability issues (Loorbach et al., 2017). Instead, they primarily represent an agenda of continuity that tries to change as little as possible in the existing system, maintaining its power relations and institutional configurations (Unruh, 2002; Avelino, 2017). That has been seen, for instance, with climate change mitigation options promoted by the fossil fuel industry, such as "clean coal" or carbon capture and storage (Ackerman and Hassler, 2008; Bäckstrand et al., 2011). These issues are not unfamiliar to land-use or agri-food system debates. While more critical experts have long argued that sustainability cannot be achieved without significant changes in agri-food systems (Frison, 2016; IPBES, 2019; HLPE, 2020), agribusiness-led pathways that supposedly address deforestation such as climate-smart agriculture or "sustainable intensification" have prevailed instead (Godfray, 2015; Newell and Taylor, 2018). In theory, they could have led to limited production without deforestation. Still, in practice the Jevons paradox has been prevalent in South America: yield and other productivity gains have driven further expansion and consolidation (Ceddia et al., 2013).

An unsustainable land-use momentum thus persists despite the climate crisis or alerts about the Amazon's imminent tipping point (Lovejoy and Nobre, 2018; Bastos Lima et al., 2021). Unruh (2002, p. 317) warns that "due to the self-referential nature of [the socio-technical regime], escape conditions are unlikely to be generated internally and [. . .] exogenous forces are probably required." Hughes (1983, p. 16) makes a similar observation in noting that "despite the momentum of systems and the inertia of motion, [. . .] contingencies push systems in new directions." He then details the impacts of World War I on US electrical systems, again stressing the role of such contextual or outside forces for systemic change. Geels (2018) defines those broader forces as elements over which regime actors have little or no influence, including cultural changes, demographics, and geopolitics.

Lock-in types: A framework for analysis

Socio-technical regimes such as fossil-based energy or industrial agri-food systems are stabilized and remain dominant due to multiple lock-in mechanisms, such as sunk investments, core competencies, and institutional commitments (Geels et al., 2017b). Geels (2019) subdivides those mechanisms into three types of lock-in which we here utilize as an analytical framework. First, there is institutional and political lock-in: regulations, standards, as well as uneven political representation in governments or private governance mechanisms that favor regime incumbents. Such structures create an uneven playing field that disproportionately benefits conservative, reformist, or incremental agendas while shunning major changes that could revamp power relations (see Bastos Lima and Persson, 2020). Second, techno-economic lock-in: investments and infrastructure that create vested interests against radical change, as well as "low cost and high-performance characteristics of existing technologies due to economies of scale and decades of learning-by-doing improvements" (Geels, 2019, p. 189). Third, socio-cognitive lock-in: livelihoods, lifestyles, social capital, and identities coalesced around certain practices. It includes what Seto et al. (2016) refer to as behavioral lock-in but also goes deeper into actors' beliefs, self-perceptions, and underlying attitudes (Trencher et al., 2020). Socio-cognitive lock-in creates mindsets that frame impressions and views, and therefore "binds" actors' rationality, hindering the acceptance or even the imagining of alternative systems (Nelson, 2008). **Figure 1** provides an illustrative scheme of our framework, which can be applied to various forest-risk commodities such as soy and palm oil.

Land Reform and agricultural expansion in the Brazilian Amazon

The case of Land Reform settlements

Brazil's Land Reform program is one of the world's largest land redistribution efforts (Filho et al., 2016). Originally launched in the 1960s, it has led to more than 3,500 Land Reform settlements in the Brazilian Amazon, involving 580 thousand families settled over a sheer expanse of 42 Mha (INCRA, 2021). Those settlements are critical for conservation because about one-third of the Brazilian Amazon's deforestation occurs within those areas (Alencar et al., 2016; Souza and Alencar, 2020; Pereira et al., 2022). However, most of that deforestation

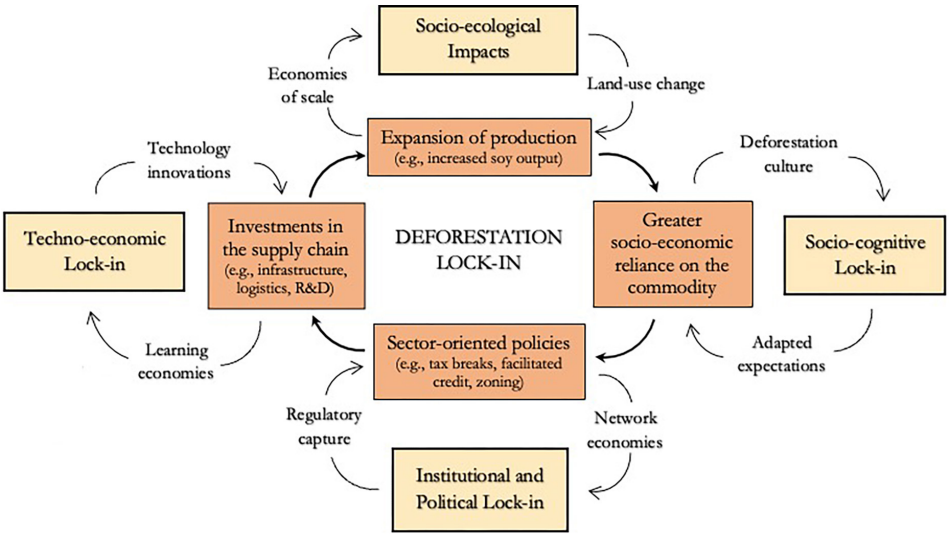

FIGURE 1
An illustrative scheme of positive feedback loops creating a deforestation lock-in from the unsustainable expansion of an agricultural commodity. Adapted from Unruh (2000).

happens through large-scale clearing (Pacheco, 2009), hinting at the illicit utilization of Land Reform plots by larger actors that evict or (sometimes forcibly) lease such areas from the settled smallholders (Alencar et al., 2016). Examining how – and why – this deforestation pattern happens is a key piece of the puzzle to understand persistent native vegetation loss in the Brazilian Amazon.

The 1960s: The origins of Brazil's Land Reform program

Brazil experienced growing social unrest in the early 1960s. Rural conflicts between large landholders and peasant organizations were prevalent, with the latter mobilizing against historical land ownership concentration that left little for smallholder livelihoods (Alston and Mueller, 2010). Such rural tensions – among others – contributed to the military coup that would keep Brazil for over 20 years (1964–1985) under a military dictatorship (Alston et al., 1999). A few months after the 1964 coup, however, the military government approved a new policy to address land ownership concentration and the related social unrest, the so-called Land Statute (Sparovek, 2003; Pereira et al., 2022).

The new legislation allowed the government to expropriate public or private areas and convert them into Land Reform settlements, where individual plots would be given to families willing to farm the land (Navarro, 2009). Those initial settlements are nowadays labeled as standard Settlement Projects (PA – *Projetos de Assentamento*), where each family receives an individual plot (Pereira et al., 2022). A new agency, the Brazilian Institute for Colonization and Agrarian Reform (INCRA – *Instituto Nacional de Colonização e Reforma Agrária*), would govern the process. INCRA would plan, implement, monitor, and provide legal rights to settler families (Sparovek, 2003). To be eligible, farmers had to meet several legal, social, and economic criteria indicating their vulnerable condition and farming livelihood. Such requirements have changed over the years, yet a focus on benefiting smallholder farming remains[2].

The 1970s–1990s: Occupying the Amazon

Public efforts for territorial occupation managed by INCRA were never formally restricted to the Amazon. Still, governments have mainly targeted that region – the country's least populated one – for settling farmers and landless rural people from more densely populated areas (Fearnside, 2005; Pacheco, 2009; Pereira et al., 2022). All along, the idea has been to offer access to land, credit, and agricultural technical assistance to Land Reform settlers while also securing land tenure for pre-existing occupations, notably on the sides of federal roads such as the Transamazônica (BR-230) and BR-103 highways in Pará State (Oliveira, 2005; Fearnside, 2007). During the 1970s and 1980s, under the nationalistic mottos of "to integrate it in order not to hand it over" (*integrar para não entregar*) and "too much land for too few people" (*muita terra para pouca gente*), Brazil's military dictatorship openly flagged the Amazon as a key region for colonization (Ribeiro, 2005). Those efforts eventually coalesced into a National Agrarian Reform Plan (PNRA, Decree 91.766) in 1985. The Amazon would become a new political arena for territorial contestations – and, quickly, a deforestation frontier.

As usual with frontiers, the Amazon was and continues to be portrayed as a "demographic vacuum," an idle land noted primarily by what it does not have (e.g., infrastructure) and its perceived economic potential (Campbell, 2015; Bastos Lima and Kmoch, 2021). It has been consistently pictured as a wilderness without civilized human presence – an idea found in Eurocentric historical descriptions (Meggers, 1971) as well as in contemporary imaginaries over the Amazon (Hecht and Cockburn, 2010). Such accounts have, of course, overlooked the Amazon's many forest societies, such as peasants (*caboclos*), rubber-tappers (*seringueiros*), small-scale "extractivist communities" (*comunidades extrativistas*), as well as riverine and estuarine populations (*ribeirinhos*), afro-descendant settlements (*quilombolas*), and multiple Indigenous Peoples (Becker, 1995; Adams et al., 2009). When not seen as outright empty, the Amazon has alternatively been presented as a "green hell," a daunting territory full of threats (e.g., wild animals, tropical diseases, and untamed nature), which belongs to no one and is up for grabs (Meggers, 1971; Campbell, 2015).

In 1988, Brazil's new democratic Constitution enshrined Land Reform as a Constitutional principle to promote equitable access to land, and in 1993 a Land Reform Act specified the legal instruments to expropriate "unproductive" areas. It targeted not only public lands but also large private farms (*latifundia*) not used for cultivation or cattle ranching. Rural social movements have been key advocates of such expropriations, notably the Landless Rural Workers' Movement (MST), created in 1984 (Wolford, 2010). Alongside other peasant organizations with their origins mostly in Brazil's more densely populated regions, they were crucial for pushing forward the Land Reform agenda (Arnt and Schwartzman, 1992). At that time, however, the Amazon was barely part of Brazil's current role as a global agricultural commodity exporter – something that would materialize in the following decades.

2 The primary criteria are the following: the beneficiary must be a farmer of legal age (18 or older) and a Brazilian citizen, and the person cannot be a public servant, be retired, or have been convicted in a judicial process. His or her family income cannot be higher than three times the minimum wage, and the farmer shall not own any previous business, industry, or another rural property in the municipality where he or she will be settled. Lastly, the beneficiary cannot be physically or mentally disabled in any way that prevents him or her from doing farming work (INCRA, 2021).

2000s-present: Turning the Amazon into a commodity frontier

Since the 2000s, Land Reform settlements in the Amazon have soared. Their role in contributing to deforestation has also remained significant despite growing environmental concerns (Malhi et al., 2008; Pereira et al., 2022). As such, in 2004 a Second National Agrarian Reform Plan (II PNRA) introduced policy changes. In the Amazon, the Plan tried to reduce settler-driven deforestation by strengthening the land rights of traditional communities such as Indigenous or *quilombola* peoples (Alencar et al., 2016). It also sought to prioritize the implementation of novel settlement modalities adapted to the Amazon, such as Agroextractivist Settlement Projects (*Projetos de Assentamento Agroextrativista* – PAE), Forest Settlement Projects (*Projetos de Assentamento Florestal* – PAF), and Sustainable Development Projects (*Projetos de Desenvolvimento Sustentável* – PDS). Unlike conventional settlements, these other modalities offer possibilities for engaging in community-based forest conservation. They are often grounded on collective territorial rights, the commercialization of non-timber forest products, and a strong cultural connection to the local landscape and biodiversity (Alencar et al., 2016). Nonetheless, conventional deforestation-based land uses remain dominant.

Land Reform has continuously brought new waves of peasants into the Amazon without successfully mainstreaming sustainable land use (Diniz et al., 2013). Instead, in typical frontier fashion (see Moore, 2000), the Amazonian landscape has become increasingly integrated into global commodity supply chains (Zu Ermgassen et al., 2022). The production of beef, leather, soy, and corn to satisfy growing market demands started to be a key driver of land-use change (Friis and Nielsen(eds), 2019; Pendrill et al., 2019). Supply-chain initiatives such as the Amazon Soy Moratorium, which major commodity traders voluntarily signed committing to stop sourcing from areas cleared after 2008, have come into place and helped reduce deforestation (Heilmayr et al., 2020). However, the moratorium does not monitor Land Reform settlements (ABIOVE, 2021). Moreover, as Rausch and Gibbs (2021) point out, there is plenty of soy-suitable land cleared before 2008 and currently used for cattle ranching in the Amazon. Thus, even without causing direct deforestation, in a system-like fashion soy expansion pushes livestock farming deeper into recently-cleared areas of the forest while capitalizing ranchers that sell their lands to move deforestation further (Arima et al., 2011). Meanwhile, state actions regarding the expansion of infrastructure, subsidized credit, and fiscal benefits have all been heavily oriented toward the interests of large agribusiness and its political leverage (Kroger, 2017; Ferrante and Fearnside, 2019). The dismantling of environmental safeguards under the Bolsonaro administration would become just the latest manifestation of the interest in removing barriers to agribusiness expansion in that region (Ferrante and Fearnside, 2021; Bastos Lima and Da Costa, 2022; Milhorance, 2022).

Fieldwork and data-collection methods

To analyze the settings and land-use practices in Land Reform areas of the Brazilian Amazon, we have reviewed the existing policies and conducted fieldwork in three settlements in Pará State. This state is especially relevant because it has Brazil's largest number of Land Reform settlements and the country's highest cumulative deforestation rate, accounting for as much as 34% of all cleared land in the Brazilian Amazon (Filho et al., 2016; INPE, 2021). In Pará, we have visited Land Reform settlements that were part of the Sustainable Settlements Project, led by the environmental NGO Amazon Environmental Research Institute (IPAM) and financed by international resources through the Amazon Fund (Souza and Alencar, 2020). Those settlements are in western Pará, a sub-region that comprises 28 municipalities, about 1.2 million inhabitants, and still has large areas of conserved forest (Souza and Alencar, 2020; see **Figure 2**). The visited settlements were founded in the 1990s and are all examples of the conventional Land Reform category (*Projeto de Assentamento* – PA). They were, however, exposed to alternative income initiatives through the Sustainable Settlements Project (e.g., agroforestry production, payment for ecosystem services) and could later report on the challenges that have historically constrained them into land-clearing and environmentally degrading practices.

We have employed a mix of qualitative data-collection methods based on semi-structured interviews and direct field observations. Initially, we engaged with IPAM representatives and researchers who managed the Sustainable Settlements Project from major cities in Pará (Belém, Santarém, and Itaituba). We then accompanied rural technical assistants in their routine of fieldwork activities in Land Reform settlements in the municipalities of Mojuí dos Campos and Aveiro, and interviewed smallholder settlers and their community leaders. The first author was hosted in multiple settler homes for 1 month, and through this experience had an intense interaction with those communities, families, and livelihoods. In this way, we have been able to engage also with actors who are usually marginalized, such as women and younger generations. We conducted a total of 25 semi-structured interviews in Land Reform settlements and participated in two community meetings, first with 40 stakeholders from two settlements and then with 15 stakeholders from another settlement. We later engaged again with leaders of social movements, smallholder associations, and producer cooperatives in Pará individually for additional interviews and two group meetings

FIGURE 2
Visited areas during the fieldwork, including Pará's capital (Belém) and four municipalities in the western part of the state. Santarém is a regional hub, while the Land Reform settlements we visited are in the municipalities of Aveiro, Itaituba, and Mojuí dos Campos.

in the municipalities of Belém and Santarém (see Table 2). All interviews were conducted by the authors directly in Portuguese. To ensure privacy and respect stakeholders' requests, the conversations were not recorded, and their statements were anonymized. Quotes are a result of on-site notetaking.

We asked all stakeholders to discuss the persistence of Amazon deforestation, while Land Reform settlers were particularly prompted to elaborate on why clearing takes place in their lands. Our expectation was to hear the often-repeated discourse that their livelihoods depend on land conversion for agriculture and that deforestation is necessary for overcoming poverty in rural areas. Such a narrative has long been prevalent in Brazil and was once again brought to the fore in January 2020, when Brazil's then Minister of Economy, Paulo Guedes, declared to the World Economic Forum in Davos that "the worst enemy of the environment is poverty; people destroy the environment because they need to eat" (Salomão and Coelho, 2020). However, the way local actors related to deforestation proved highly different, more telling, complex, and nuanced than that mainstream, elitist and enduring belief.

Deforestation as an emergent property: Systemic drivers of land use change

Institutional and political lock-in

Brazil's land policy framework contains crucial elements conducive to deforestation lock-in in the Amazon. Two legal principles in the country's Land Reform legislation work as institutional drivers of forest clearing: the notions of the "land's social function" and the need for "improving the land" to validate its possession and secure settler rights. They have been legally established in Brazil since at least the 1964 Land Statute and were later enshrined in the country's (current) 1988 Constitution (Article 186). The land's social function is fulfilled when activities in a rural property provide for the "rational use of natural resources" while conserving the environment and complying with labor laws. Farms that fail to fulfill such a function can be expropriated and redistributed for Land Reform. "Improvements to the land," in turn, are usually the way to demonstrate that the social function is being met. In Land Reform settlements, that principle is generally

TABLE 2 Engagement with stakeholders in Pará State, Brazil.

Municipality	Description	Number of people	Contributions to the research
Belém	Project coordinator, project manager	2	An overview of the Sustainable Settlements Project, its goals and results
	Local NGO researchers	5	Analysis of drivers of Amazon deforestation in Brazil
	Collective meeting	15	A general account on the political context in Pará State and its local initiatives
Santarém	Regional and technical coordinator, farming technicians	4	Insights on technical farming practices for improving sustainability on the ground
	Local NGO researchers	2	Reflections on the obstacles for promoting sustainable land use in Pará and the Amazon
	Collective meeting	25	Information on the challenges and opportunities for innovations in western Pará
Mojuí dos Campos	Family farmers	6	Local perspectives on the obstacles to sustainable practices in Land Reform settlements
	Collective meeting	40	Discussion on the challenging local reality of this specific case
Itaituba	Regional coordinator and farming technician	2	Assessment of technical practices for improving sustainability on the ground
Aveiro	Family farmers	10	Local perspectives on the obstacles to sustainable practices in Land Reform settlements
	Collective meeting	15	Insights on the local reality of this specific case
Total		31 interviews and 95 people engaged in collective meetings	

interpreted as a need to make productive use of the area through some form of economic activity (Filho et al., 2016). "Improving" the land and fulfilling its "social function" thus typically entails deforesting native vegetation and replacing it with agriculture or livestock farming to show that some "productive activity" is taking place. Although the newer 2004 guidelines of the II National Agrarian Reform Plan identify conservation-based economic activities such as ecotourism also as "improvements," pursuing such alternative land uses and having them effectively recognized remains difficult – and rarely implemented – due to other contextual factors detailed below (Alencar et al., 2016).

In the case of Land Reform settlements, the legal compulsion to "improve the land" is particularly critical because that is a requirement for tenure. Interviewed settlers observed that most areas they were sent to had pristine native vegetation cover. However, to ensure their access to land titles, they had to prove they were conducting economic activities to meet the land's social function, which most often meant farming based on land-clearing (see Alencar et al., 2016). These legislative requirements reinforced by Constitutional prescriptions create legal antagonism toward change at the highest level. They produce a ripple effect over other policies (e.g., land titling requirements) and cannot be easily addressed through ordinary policy-making, only through a much-harder Constitutional amendment.[3] That kind of institutional driver also strengthens – and in a way gives legal blessing – to the conventional mindset of deforestation as a necessary cost for development. Many settlers reported even being trained by public officials on how to use chainsaws to cut trees more efficiently. They were requested to deforest at least half of their plots as proof of economic activity (Interviews). "*We considered it a big accomplishment when we were able to deforest two entire hectares with our bare hands*," a Land Reform settler pointed out.

Besides the letter of the law, Brazil's land-use regulations and politics are dominated by agribusiness actors interested in forest clearing for agricultural expansion (Kroger, 2017; Søndergaard, 2020). The country's economic history is rooted in large-scale agriculture, both export-oriented plantations and extensive cattle ranching, and global demand for commodities has once again put that sector at the forefront of Brazil's economy (Svampa, 2015). Its Congressional "rural caucus" (*bancada ruralista*) is one of the country's mightiest political forces, which – especially since the adoption of the New Forest Code in 2012 and, later, with the Bolsonaro administration (2019–2022) – has achieved gradual flexibilization of environmental and land-clearing regulations (Kroger, 2017; Ferrante and Fearnside, 2019; Trancoso, 2021; Bastos Lima and Da Costa, 2022). Those politicians, government officials, farm lobbies, and (agro)industry players form a policy network that systematically waters down environmental regulations to safeguard sectoral vested interests, increase their power, and thus create a political lock-in antagonistic to change (see Normann, 2017).

Growing political leverage from Brazilian agribusiness actors connected to the global agri-food regime reveals increasing signs of regulatory capture (Hopewell, 2014; Sondergaard, 2018; Bastos Lima, 2021). Protected areas have been progressively reduced or downgraded, particularly after 2008 (Bernard et al., 2014), while agribusiness lobbies for laxer land-use regulations have been continuous (see Portela, 2022). Notably, Sant'Anna and Costa (2021) have shown that regular

3 Constitutional amendments (*Projetos de Emenda Constitucional* – PEC) in Brazil do come by. They are relatively routine, with at least a few being voted every year. However, they require a qualified, three-fifths majority in both houses of Congress, followed by Presidential sanction. That means they are hardly ever achieved on socially or politically divisive issues.

amnesties to those who illegally deforest have fostered a near-certainty of pardon that incentivizes Amazon clearing. Such leniency has both regulatory and enforcement dimensions. For instance, while research demonstrates that on-the-ground monitoring and enforcement can substantially dissuade clearing (Börner et al., 2014), only 1% of the deforestation fines issued by environmental authorities in the Brazilian Amazon between 1995 and 2019 were ever paid (Pagenotto and Arroyo, 2021). Likewise, Coelho-Junior et al. (2022) note that despite substantive increases in satellite monitoring capacity, action from Brazil's main environmental agency on deforestation alerts has been scant (limited to 1.3% of the alerts) due to budget cuts and internal mismanagement in the past years. As a local NGO researcher summarizes, exposing the spirit of such capture, "*Public policies themselves encourage deforestation and provide amnesty for land uses that do not comply with the [environmental protection] law.*"

Settlers' perceptions on the ground corroborate the view of the Amazon as a permissive land where deforestation is state-sanctioned, stimulated by the authorities – and that, even when it is overdone, transgressive actions anyway will be "okayed" sooner or later. They see those who abide by environmental laws as fools wasting time, effort, and resources, given that those who disregard the legislation are rewarded by the government (Interviews). Such confidence, spurred by knowledge of the dominant pro-agribusiness politics in place, underscores the prevalent view that one reaps more benefits from breaching the (environmental) law than by complying with it. Most farmers thus bother little with conservation, instead falling in line with the institutional setting that favors deforestation.

Techno-economic lock-in

Numerous forms of techno-economic lock-in bind land users to deforestation-driving practices in the Brazilian Amazon. First, access to credit is uneven. As noted by Unruh (2000), dominant actors benefit not only from the re-investment of their own profits (in a positive feedback cycle) but also from financial institutions that become risk-averse and tuned to business as usual. Indeed, access to credit (and its eventual requirements) has shown to highly steer land uses and the economic activities adopted in the Brazilian Amazon (Assunção et al., 2020). Public credit is particularly crucial for families in Land Reform settlements because they rarely have their own capital, can hardly obtain loans at private banks, and therefore depend on accessing public finance. Nevertheless, settlers report that getting credit for any form of "alternative" agriculture or conservation-based economic activity is notably hard. As a local NGO representative observes, "*The credit lines available to the producers are totally based on conventional [large-scale] models and do not have socio-environmental criteria. It would be important to have differentiated interest rates for funding initiatives with some level of sustainable production.*" Banks demand a fully developed agricultural project attached to the credit application, entailing a high upfront cost that such smallholders generally cannot afford. Even when that can be put together, settlers report that banks frequently deny their requests as "too risky" (Interviews). As an interviewee bluntly puts it, "*[t]here is an incompetence of the state to resolve this situation that should be simple.*" Meanwhile, credit for conventional activities that usually drive deforestation – such as livestock farming or swidden agriculture – is much easier to access. Settlers therefore become economically bound to engaging in conventional land uses based on clearing even when willing to pursue something else.

Second, there are technical constraints imposed by either absent or biased rural extension and agricultural assistance. Research in Brazil has shown that agricultural technical assistance is critical for smallholders in general and Land Reform settlers in particular (Leite et al., 2021). While large-scale farmers cultivating major crops such as soy can obtain such services privately, from the state, or through industry associations, smallholders in the Amazon generally lack them (see Stabile et al., 2020). In the case of Land Reform settlements, Brazil's dedicated agency (INCRA) is supposed to provide those services, but due to a lack of personnel or funds, it hardly ever delivers. When at all provided, technical support tends to come from other government agencies involved with conventional, large-scale agriculture. Settlers regard such support as intermittent, unreliable, and focused on either mainstream monocultures or cattle ranching (Interviews). Besides, it is usually based on "green revolution" technology packages that include substantive use of expensive chemical inputs and seeds that do not adequately reproduce, and which therefore need to be bought over again every year (Interviews). Indeed, rural extension has been successfully used in Brazil for changing farmer practices, but only along the lines of greater intensification through heavier chemical usage, in services oriented toward the needs of larger and more capitalized landowners (see Bragança et al., 2022).

Meanwhile, alternative ways of cultivating the land – such as with organic inputs, native seeds, or biological pest control – are generally out of tune with the government-provided technical assistance. Some settlers have reported considering agroforestry systems, for example, or integration between agroforestry and cattle ranching, but having rural extensionists not even acknowledge such alternatives as feasible. As predicted by the theory, there is an apparent path dependency in the very training of such technicians. As a result, settlers receive little or no information about more sustainable land uses and, instead, are prompted to adopt environmentally degrading practices. A local community leader sums up the issue by critiquing

the technical support occasionally provided by the government as "*neither efficient nor adequate, because [the approaches] are assistentialist, do not teach how to think, do not involve the people, do not transform, [and] do not form conscience*." Forest-friendlier economic activities and land uses thus become mostly a mirage, as settlers hardly have the financial or technical means to pursue them.

Third, there are critical market access barriers for engaging in any non-subsistence economic activity other than cattle ranching or, in some cases, leasing the land to (well-capitalized) soy growers. Transport and other built infrastructure are generally limited in the Amazon and extremely precarious in Land Reform settlements, severely impairing the local settlers' capacity to sell their products. There are typically no paved roads connecting the settlements anywhere; plots are far from one another and even farther away from towns or cities where goods could be traded. No public transport is available, and during the rainy season (December–May) there are recurrent mudslides that make unpaved roads nearly or totally impassable. Often, there is no internet access or mobile phone service, limiting such settlements' capacity for economic exchange even more.

The technical and physical obstacles this context creates for settled farmers are numerous. For one, inadequate transport infrastructure renders the cultivation of perishable crops such as fruits, nuts, or other forest products economically unviable and essentially limited to subsistence or to exchange amongst neighbors. According to a local environmental analyst from a civil society organization, "*It is flabbergasting. There are tax breaks and fiscal incentives here for producing beef burgers, but not for structuring value chains around Amazonian vegetable oils and butters.*" Integration with local markets – let alone regional, national, or international ones – becomes hampered as it is virtually impossible to sell anything outside the community itself. That contrasts with the increasing availability of dedicated infrastructure for soy and beef in the Amazon, such as Cargill's local grain terminal in the Port of Santarém (PA) and a growing number of meatpacking processing units in the region.

Settlers, therefore, often opt for livestock farming, as cattle can be transported alive for up to a week (Interviews). Cattle ranching, however, typically demands larger clear-cut areas open for pasture – unless the livestock farming utilizes alternative methods which, as seen, entail skills not usually made available to these settlers. Their main livelihood option thus is to become suppliers for the beef-leather agroindustrial complex – the number-one deforestation driver in the Amazon (see Skidmore et al., 2021; Mammadova et al., 2022; Zu Ermgassen et al., 2022).

Alternatively, in less remote areas those settlers illegally lease their plots to soy growers. As Land Reform settlers are not allowed to rent out the land itself, they nominally lease their "improvements" (*benfeitorias*) on the land (e.g., a house) under informal contracts. Notaries would anyway be hundreds of kilometers away, and such formalities are broadly disregarded in the region. Soy from these places will not find it hard to reach markets indirectly (see Zu Ermgassen et al., 2022) and, again, these Land Reform areas are not monitored by the Amazon moratorium. Many settlers thus lease out and leave, to the nearest city or back to where they originally came from and may still have some social network for support (Interviews).

Socio-cognitive lock-in

Most farmers in Amazonian Land Reform settlements originally come from elsewhere in Brazil – often from its temperate southern regions. Such regions are remarkably different from the Amazon not only biophysically (e.g., soil composition, rain patterns, and temperature), but they are also more urbanized, have shorter distances, and have more developed markets and infrastructure. Interviewed settlers recurrently mentioned the challenges of arriving in a completely new and unknown area, having neither agricultural knowledge about the new place nor adequate extension support. Lacking such context-specific training, settlers utilize the knowledge they already have. Usually, that means farming practices from southern Brazil, such as slash-and-burn agriculture to provide organic fertilization in a newly cleared field. In the Amazon, however, the rainforest soil is comparably much poorer; the land quickly degrades whenever the vegetation is removed. Without proper technical assistance, it soon becomes unusable for agriculture after only a few harvests. As such, many settlement areas were deforested but soon abandoned afterward, with the selling or leasing of the lands. Many settlers thus emigrate to the cities, ceding their plots – usually below market price – to commercial enterprises that can utilize the soil for input-intensive agriculture. That has resulted in the expansion of soy monoculture in Land Reform settlements, which often goes unnoticed as these areas are not covered by private-led monitoring systems or voluntary commitments such as the Amazon Soy Moratorium (ABIOVE, 2021; Molinari et al., 2021).

Those dynamics are inserted in a broader culture of deforestation as development in Brazil, as elsewhere (see Russo Lopes et al., 2021). There is growing interest in understanding the role of culture and social norms in land-use change – intangible drivers, after all, shape human behavior and often require many years to change, when not decades or centuries (Williamson, 1997; Unruh, 2000; Le Polain de Waroux et al., 2021). The idea of "improving the land" still contributes to an enduring view of native vegetation as essentially useless, something deeply entrenched in Brazilian society (Bunker, 1988; Hochstetler and Keck, 2007). That has created what could be called a deforestation culture in Brazil, where conservation is primarily seen as a cost (and a waste), as opposed to land-use change for farming, viewed as a sign of development (Hoelle, 2015).

Building on that dominant view, Brazilian agribusiness has successfully framed itself as the country's main driver of economic growth, while occluding all socioenvironmental impacts associated with it (Lahsen, 2017; Santos et al., 2019; Bastos Lima, 2021; Russo Lopes et al., 2021). That translates into systematic attempts to foster a "petty agribusiness" (*agronegocinho*) mindset among family farmers, who see grandeur in export-oriented cash-crop agriculture and at times wish it for their smallholdings too (see Hoelle, 2015; Alencar et al., 2016). Among those ideal images is the "rainforest cowboy," espousing an attitude generally unconcerned with conservation while affectively connected to livestock farming as a cultural symbol and a source of identity (Hoelle, 2015). From the perspective of an interviewed family farmer and social movement coordinator, "*There are many people who think the cowboy is a social status — the vision of livestock as something successful — , that wearing the boot, the belt, and the hat is what they want to do.*" Such lifestyle perceptions are critical for the choices made by Amazonian farmers more broadly (Garrett et al., 2017). From the consumption side, in turn, there is a positive attitude toward beef consumption in Brazil (whose domestic market absorbs as much as 80% of the country's production), notably among men (Ruby et al., 2016). The more such conventional farming practices like cattle ranching spread and gain socio-economic relevance, the more socially and economically attractive a "rainforest cowboy" attitude becomes. "*Becoming a rancher is seen as a sign of prosperity, of social ascension*," a local Pará researcher sums up.

Such dominant attitudes and views of course influence Land Reform settlers. They are caught up in a discursive battle between the fierce nationalistic defense of agribusiness and growing awareness of environmental issues among the Brazilian public (see Lahsen, 2017; Bastos Lima, 2021). Despite the emerging salience of sustainability concerns, changing the profoundly entrenched way of seeing the forest as a wasteland and deforestation as a synonym of development is hard. Land Reform settlers reported finding it challenging to deal with now being framed by some as villains for deforesting the Amazon, given they have been steered and incentivized to do so all along (Interviews). As a settler and social movement leader puts it, "*[t]oday the peasants look like the deforester, the oppressor, because of this social construction.*" After all, they were brought to the Amazon to "tame the wild north" by turning forest areas into "productive" lands for the country's benefit. They used to be seen as pioneers – and to be praised for that – and feel unfairly shunned now as environmental vandals. Settlers often view the changing public attitude toward deforestation as a disregard for their previous efforts, a betrayal of the rules that were agreed upon, and a disrespect for their rights (Interviews). There is, thus, socio-cognitive inertia in the old ways of thinking, still tied to a formula of "development" based on deforestation.

Discussion

Lessons from Land Reform settlements

Our assessment shows how persistent deforestation in Brazil's Land Reform settlements – as in the Amazon more broadly – is hardly the sole work of individual drivers. It is the outcome of a complex land-use regime that includes cultural, technical, institutional, and economic elements. Deforestation lock-in can be said to stem from local poverty and governmental or market neglect toward alternatives as much as from infrastructural constraints, entrenched sociocultural drives, and institutions aligned with politically influential agribusiness interests. Demonstrably, such a dominant configuration has not just failed to curb tropical deforestation – the regime, in fact, actively pushes for it. In short, what we have is the inertia of a system that has acquired momentum. Its goals – colonization, occupation, deforestation, the expansion of commodity agriculture – have all become entrenched. Increased returns over the past decades have solidly consolidated it, and the incumbents resist change. That is in line with the observation that such systems can accelerate or decelerate – as indeed has happened to deforestation in the Brazilian Amazon – but that the goals and direction set early on become increasingly hard to modify (see Hughes, 1983).

Indeed, we see multiple self-reinforcing interactions between those regime components. For one, the increasing prowess of meatpacking and grain conglomerates, together with the image of the cattle and soy sectors as economic heavyweights, make them all the more attractive as a livelihood, both for income and in the pursuit of perceived social ascension. Such societal buy-in supports the political defense of these industries and the provision of policy incentives, which in turn facilitates their expansion and increased social appeal. In tandem, increased grain storage and shipping infrastructure alongside dedicated credit facilitate soy expansion, which becomes more economically relevant in Amazonian states and, thus, invites greater social and political support.

It would be naïve to expect more sustainable value chains – such as those based on native Amazonian goods – to naturally take off as if local producers were unencumbered by institutions as well as technical and economic disadvantages. As an Amazonian NGO representative argues, "*We cannot place on the shoulders of the smallholders the task of subverting the whole machine, the infrastructure that exists for conventional [large-scale] agriculture.*" For instance, Pereira et al. (2022) recommend having more standing-forest modalities of Land Reform settlements to stem Amazon deforestation, and our findings support that recommendation. However, we also demonstrate that such a policy change could be ineffectual

without further changes elsewhere, such as in the techno-economic means to make those alternatives viable in practice. In the end, settlers still find in conventional agriculture or cattle ranching the easiest ways to make a living and demonstrate economic use of the land.

Before moving into potential ways forward, we would like to point out three lessons that may be of value for sustainability transitions scholarship, particularly its application to the problem of tropical deforestation. First, this case on Land Reform settlements vividly illustrates how lock-in is not simply an intra-system phenomenon; rather, it is critical also for those on the fringes of it, who sometimes would not want to be part but anyway get caught up and become minions willingly or unwillingly contributing to expand the system. Land Reform settlers are constrained to either embrace deforestation-based land uses or make their resources available for commodity expansion through land leases for large-scale soy and cattle (see also Alencar et al., 2016). The words of a settler are illustrative,

> "We have identified several [settler] communities that have disappeared, let alone those that have only three people left and the ones that are shrinking. We feel very sad when we realize it. Some become rural slums (favelas), where they only live but do not manage to farm. We all risk disappearing with soy expansion and this leasing to soy farmers and land sales, too. [Settlers] cannot sell the land, but they sell their properties and become laborers for soy agribusinessmen. Then everything gets knocked down. There is great insistence of all forms to acquire those lands. And on top of it there is the question of agrichemicals [contamination]. That all leaves us very worried for our youth." (Interview).

Transition scholars have long noted that dominant actors are not inert, as if they were helpless and simply "going with the flow;" instead, they continually are actively securing their dominant positions, expanding on advantageous power relations, and meeting their interests – in a quite aware political act (Geels, 2014; Avelino, 2017; Bastos Lima, 2021). That is not to say they could revamp everything without constraints, but – by definition – regime incumbents have greater control and benefit disproportionately from the system (Avelino, 2017). Subordinate actors such as Land Reform settlers, in contrast, have far less agency or power and become locked into the dominant socio-technical regime much less voluntarily, sometimes against their will as the only way to get by. To those, the metaphor of inertia and mechanical move forward, which Geels (2014) critiqued in the case of dominant actors, may be much more applicable. As such, the socio-technical regime can be thought of as a whirlpool, a vortex that pulls and binds other actors to either become part of it or at least avail their resources for its expansion.

Second, Brazil's case clearly shows that politico-institutional lock-in is not limited to regulatory capture (something typical in carbon lock-in and widely discussed in the transitions literature; see Seto et al., 2016; Avelino, 2017; Geels et al., 2017a). In this case on tropical deforestation, lock-in includes a crucial dimension of enforcement. Absent, lax, or selective policy implementation may be even more critical than the regulations *per se*, as Brazil has plenty of laws that exist on paper but do not materialize in reality (e.g., fines and other punishment for environmental crimes, INCRA's duty to provide tailored rural extension services and technical assistance to Land Reform settlers) (see Trancoso, 2021; Coelho-Junior et al., 2022). It is important to note that such implementation issues have a dual nature, of both permissiveness and neglect (see Bastos Lima and Kmoch, 2021). Land Reform settlers go without many of the rights they legally have, while the monitoring and enforcement of command-and-control measures have waxed and waned in Brazil depending on governmental whims and who is in power – regardless of whether the regulations themselves have changed or not. Much more scholarly attention may be needed to the dimension of enforcement in transitions theory (and critically for addressing deforestation lock-in), as most of the literature so far has focused on the energy transition case and in the contexts of developed countries, where lack of enforcement may be a less salient issue (see Köhler et al., 2019).

Third, it is nearly impossible for Land Reform settlers and other Amazonian smallholders to escape the lock-in alone. The transitions literature shows that, as regimes tend to reinforce themselves, change usually comes through contingencies or outside pressures (Hughes, 1983; Unruh, 2002; Köhler et al., 2019). Therefore, international actors may have a crucial role to play. While deforestation lock-in arguably has regional specificities (perhaps more so than carbon lock-in, largely treated as a ubiquitous phenomenon), international trade, finance, and the global agri-food regime have a significant responsibility in driving tropical deforestation worldwide (McMichael, 2012; Pendrill et al., 2019). In the Brazilian Amazon's case, that is mostly through the financing and consumption of commodities such as beef, soy, and minerals exported primarily to China and Europe (Galaz et al., 2018; Pendrill et al., 2019; Zu Ermgassen et al., 2020b; Reis et al., 2021). There is a sensitive shift in Europe and elsewhere toward greater responsibility or "harder" accountability in sourcing such forest-risk commodities (Schilling-Vacaflor and Lenschow, 2021). However, it remains to be articulated how voluntary zero-deforestation commitments and mandatory due diligence legislation in certain consumer regions may effectively help change the incumbent land-use regime in the Amazon (and elsewhere), beyond the cleaning of individual supply chains. Articulating such a strategy for a transition is especially key because such concerned buyers represent only a small share of the global market for forest-risk commodities (Marín Durán and Scott, 2022).

Toward a zero-deforestation transition

Socio-technical regimes are constituted, among others, of policy mixes that favor and support mainstream practices. Therefore, institutions represent a pathway for changing such practices. In the case of land use, many authors have argued for combining various interventions – command-and-control actions, supply-chain policies, economic incentives, etc. – in mixes that can operate synergistically to address tropical deforestation (see Lambin et al., 2014; Bastos Lima et al., 2017; Carrilho et al., 2022). Some have gone further to discuss also the most effective sequencing for such measures (see Furumo and Lambin, 2021). What is clear from transitions theory is that successful action must include a measure of both "creation" and "destruction" elements (Kivimaa and Kern, 2016). That is, a transition requires a strategy to disrupt the incumbent regime while scaling up alternatives (see Geels, 2018).

Table 3 summarizes some key constitutive elements of the deforestation lock-in we identified in Land Reform settlements. We also point to possible intervention options targeting specific aspects of the dominant regime or filling existing gaps. For instance, Assunção et al. (2020) showed that introducing environmental requirements for rural credit during some years in Brazil had perceptible effects on reducing Amazon deforestation. Most such interventions have already been tried in some specific contexts in one way or another, yet they have generally fallen short of achieving a sustained transformation. As seen, regimes are resilient, and their internal coherence means that change requires addressing its various elements simultaneously rather than in a piecemeal approach (Köhler et al., 2019). In the same way a mix of policies and norms has been acting to uphold the current deforestation regime, new mixes are needed to challenge it and foster something new.

But what is that "new" which is being sought? When discussing ways of escaping lock-in, Unruh (2002) distinguished three types of purported solutions: (1) end-of-pipe approaches, which try to address negative externalities without shifting the system internally (e.g., carbon capture and storage in the case of energy systems); (2) continuity approaches, which change the system only marginally and perhaps not meaningfully enough; and (3) discontinuity ones, which would see the end of a regime as-it-is and have it replaced by something else. One could think of those as features not of individual policies but as an emergent property of the mix of implemented interventions. For instance, Brazil's command-and-control actions to curb deforestation arguably amounted to an end-of-pipe approach. It reduced the deforestation rate between 2004 and 2012 without seeking to change the land-use regime but to harness its expansion, especially incentivizing a better use of previously cleared lands alongside yield improvements. It proved to be a fragile arrangement at best, gradually falling apart in the 2010s. Over time, regime incumbents strengthened their politico-institutional lock-in and dismantled their restraints from within the government, culminating with a free hand in the Bolsonaro administration (2019–2022) (West and Fearnside, 2021; Milhorance, 2022).

Currently, the critical external pressure that may aid in breaking the Amazon's deforestation lock-in is the groundswell

TABLE 3 AS forms of deforestation lock-in in Land Reform settlements of the Brazilian Amazon.

Deforestation lock-in	Concrete elements	Potential interventions to destabilize the deforestation regime
Institutional and political	Legal incentives to deforest in Land Reform settlements. Agribusiness dominance in Brazilian politics. Lax enforcement of environmental law in frontier regions and of public support smallholders should receive. Public policies that regularly give amnesty to those who clear forests.	Promotion of conservation-based land uses that secure settlers' tenure. Due enforcement of environmental regulations and smallholders' legal right to state support. Policy incentives to sustainable production (e.g., agroforestry) and disincentives to cattle ranching or monoculture expansion. Greater inclusion of smallholder representatives in policymaking and politics. Empowerment of Indigenous and traditional communities as land stewards through strengthened collective land rights, sovereignty, and effective participation in politics and policymaking.
Techno-economic	Uneven access to public credit and other finance. Biased technical assistance toward conventional land-use practices. Market access barriers to smallholders.	Inclusion of sustainability criteria in credit risk assessments. Training of rural extensionists in sustainable land-use practices. Institutional support for the commercialization of smallholders' production.
Socio-cognitive	Agricultural practices unsuited to the Amazon. A deforestation culture that views land-use change as development. A prevalent "rainforest cowboy" attitude socially related to key deforestation-driving activities such as cattle ranching.	Promotion of a conservation ethic in rural settings, with rural education highlighting the importance of sustainability. Update the social understanding of "development" to emphasize inclusiveness, with the cultural valorization of smallholder farming as providers of Brazil's staple foods (e.g., rice, beans, and cassava) and, thus, its food security. Expose large-scale commodity production as a corporate-controlled sector capturing public regulations and the country's resources to meet its vested interests at the expense of the public good of present and future generations.

of demand-side commitments not to source commodities from recently cleared lands. They have helped establish the connection between distal drivers of deforestation (i.e., consumer demand) and the global trade and supply-chain systems that enable and uphold the lock-in. However, whether those commitments will give rise to continuity or discontinuity approaches remains unclear. On the one hand, because they emerge from actors that are part of the regime, they configure what Hunter et al. (1994) called "intra-system innovations." Those typically are incremental solutions to new external pressures, such as Europe's increasing concerns with "imported deforestation" (see Geels et al., 2017a; Bager et al., 2021). They may weaken the reproduction of some regime elements but leave untouched the food systems, consumption patterns, or soy and cattle's dominance in Amazonian agricultural land use and rural development strategies (see Delabre et al., 2020; Smallwood et al., 2022).

That is problematic because besides having other significant environmental impacts (e.g., pesticide contamination), soy is an exclusive crop that takes land while leaving millions in search of livelihood options in the Amazon – people who end up swelling urban slums or frequently in activities such as illegal logging and wildcat gold mining (see Siqueira-Gay and Sánchez, 2021). Moreover, supporting cattle as a main rural development avenue for the Amazon means sustaining the same "rainforest cowboy" culture whose socio-cognitive drives have antagonized forest conservation and provided societal support to anti-environmental political forces.[4] It is a tenuous arrangement at best, aggravated by the limited uptake of zero-deforestation commitments, which still leave out much of Brazil's large domestic market, other non-forest ecosystems, and major international buyers besides Europe. As stand-alone policies, current demand-side measures are therefore likely to represent continuity approaches.

Nevertheless, such commitments can still become part of a broader mix of interventions that may achieve bigger change. A transition indeed refers to a "discontinuous shift to a new trajectory and system" (Geels and Kemp, 2007, p. 441). As Delabre et al. (2020, p. 6) put it, counteractions to undo the lock-in may need to redress power imbalances, notably by lifting vulnerable stakeholders up. Thus, for discontinuity, concerned actors – including those behind or advocating for more zero-deforestation commitments – may wish to pay greater attention to the "creation" part of the equation, i.e., support toward sustainable niches that may eventually replace the incumbent regime. For example, Medina et al. (2022) have shown that international support has been critical for the success of many locally developed land-use alternatives in the Amazon (see Brondizio et al., 2021). They comprise many socially inclusive value chains that keep forests standing, based on native Amazonian products now being considered under bioeconomy and sociobiodiversity umbrellas (Abramovay et al., 2021; Bastos Lima and Palme, 2022). How such niche initiatives can interact with demand-side measures to gain scale and achieve a sustainable zero-deforestation transition remains a key research frontier. More studies are needed on discontinuity mixes that combine the regime-destabilizing effect of deforestation-free supply chain policies with incentives for promoting and scaling up innovative rural development approaches and land-use systems.

Conclusion

This article has applied a sustainability transitions lens to analyze persistent Amazon deforestation in Brazil. Focusing on Land Reform settlements as a case study, the analysis identifies a structural and multi-faceted problem. No individual driver is solely responsible for forest loss in those settlements; instead, it is a systemic issue that can only be sustainably addressed as such. Illustrating what may well apply to a greater or lesser extent elsewhere, we expose a combination of techno-economic constraints, sociocultural drives, and institutional factors that have jointly created a deforestation lock-in in the Amazon. Curbing it therefore requires more than simply avoiding forest-risk commodities or punishing wrongdoers – a more comprehensive approach is needed with strategic thinking toward a sustainable land-use transition. That is pivotal for the region and the globe, given the Amazon's imminent tipping point and worldwide impacts. As societies push for decarbonization in energy systems historically built around fossil fuels, a comparable effort is required to move away from land-use regimes developed over centuries around deforestation. Indeed, in tropical countries with land-use change as their primary source of greenhouse gas emissions, this transition may be even more critical for climate change mitigation than the energy one.

Our conclusions are threefold, with some recommendations and avenues for further research. First, we have shown that sustainability transitions and lock-in theory offer a valuable lens for analyzing deforestation. Delineating the scope of land-use or agri-food systems is inherently challenging, particularly given the transnational nature of material and capital flows. Therefore, instead of trying to capture the entire regime, case studies may help make the research more manageable. It may also be worth circumscribing a coherent sub-region in a landscape, without losing sight of its long-distance connections. In our case on Land Reform settlements, we have shown how it is not so much the beneficiaries or dominant actors themselves who are locked-in, for these generally control the current system's goals and pursue them deliberately. Rather, it is mostly vulnerable actors, such as Brazil's Land Reform settlers, who

4 As of 2022, the vast majority of agribusiness people, ranchers and large-scale farmers remained vocally supportive of Jair Bolsonaro's reelection bid and of his anti-environmental political platform (Soares, 2022; see also Milhorance, 2022).

get entangled by their forceful contexts and become locked into environmentally destructive practices.

Second, we have seen that the existing regime is likely to repel any loose, piecemeal interventions if they are not introduced under a more holistic or deliberate strategy. Trying to address individual drivers such as specific policies, techno-economic constraints, or cultural factors without contemplating the regime's internal coherence – and resilience – invites the incumbents' resistance without necessarily achieving the desired transformation. Instead, concerted action must target multiple regime elements at once through policy mixes. They can be thought of as strategic elements that are to act synergistically toward a zero-deforestation transition. In this regard, much more research is needed on regime destabilization in the case of tropical deforestation – in the Brazilian Amazon and elsewhere. Transitions theory has a vast scholarship and conceptual toolkit (e.g., regime destabilization, niche formation, and transition acceleration) that makes this one a promising research avenue.

Third, we show that sustainability initiatives such as zero-deforestation supply-chain policies are yet to help address systemic issues on the ground meaningfully. Demand-side commitments expose long-distance connections and may put pressure on certain regime elements, but alone they are likely to fall short of igniting a transition. Until they build synergies with niche innovations – i.e., alternative land-use systems that can eventually be scaled up – they will be solutions of continuity that leave the regime broadly unchanged and, thus, ready to accommodate itself to such pressures. We have teased out the multiple elements of deforestation lock-in in the Brazilian Amazon; now, there is a need to identify innovations that address them and may also tap into the political momentum around a zero-deforestation transition. How to strategically build such synergies remains a crucial area for further research. We have shown how deforestation is an outcome of a coherent self-propelling system that has unfortunately gained momentum. Only concerted strategic action can counter it, while there is time.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The research involving human participants was reviewed, approved, and conducted according to the Ethical Guidelines of Stockholm University and University of Amsterdam (Approval ID: 2019-FW_OTHR-10187). All participants provided their informed written consent, and no personal data were collected. All references to the interviews have been fully anonymized to preserve the stakeholders' identities.

Author contributions

GR: conceptualization, formal analysis, investigation, methodology, and writing – original draft, review, and editing. MB: conceptualization, formal analysis, funding acquisition, methodology, and writing – original draft, review, and editing. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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