**Article:**

Reis, Tiago, de Faria, Vinicius Guidotti, Russo Lopes, Gabriela et al. (6 more authors) (2021) Trading deforestation - Why the legality of forest-risk commodities is insufficient. Environmental Research Letters. 124025. ISSN 1748-9326

https://doi.org/10.1088/1748-9326/ac358d

ENVIRONMENTAL RESEARCH
LETTERS



# Trading deforestation - Why the legality of forest-risk commodities is insufficient

To cite this article before publication: Tiago N. P. dos Reis *et al* 2021 *Environ. Res. Lett.* in press https://doi.org/10.1088/1748-9326/ac358d

# Trading deforestation - Why the legality of forest-risk commodities is insufficient

**Authors:** Tiago N. P. dos Reis[1,7*], Vinicius Guidotti de Faria[2], Gabriela Russo Lopes[3], Gerd Sparovek[4], Chris West[5], Raoni G. Rajão[6], Mariana Napolitano Ferreira[7], Marcelo M. S. Elvira[7], Raul S. T. do Valle[7].

**Affiliations:**

[1]Earth and Life Institute, Université Catholique de Louvain; Place Louis Pasteur, 3, bte L4.03.08, Louvain-la-Neuve, 1348, Belgium.

[2]Instituto de Manejo e Certificação Florestal (IMAFLORA); Piracicaba-SP, 13426-420, Brazil.

[3]Center for Latin America Research and Documentation (CEDLA), University of Amsterdam (UvA); 1018 WB Amsterdam, the Netherlands.

[4]GeoLab, Universidade de São Paulo (USP); Piracicaba-SP, 13418-900, Brazil.

[5]Stockholm Environment Institute York, Department of Environment and Geography, University of York; York YO10 5NG, United Kingdom.

[6]Universidade Federal de Minas Gerais (UFMG); Belo Horizonte 31270-901, Brazil.

[7]WWF-Brazil; Brasília-DF, Brazil.

* Corresponding author. Email: tiago.reis@uclouvain.be

**Abstract**:

Consumer countries and blocs, including the UK and the EU, are defining legal measures to tackle deforestation linked to commodity imports, potentially requiring imported goods to comply with the relevant producer countries' land-use laws. Nonetheless, this measure is insufficient to address global deforestation. Using Brazil's example of a key exporter of forest-risk commodities, here we show that it has ~3.25 Mha of natural habitat (storing ~152.8 million tons of potential $CO_2$ emissions) at a high risk of legal deforestation until 2025. Additionally, the country's legal framework is going through modifications to legalize agricultural production in illegally deforested areas. What was illegal may become legal shortly. Hence, a legality criterion adopted by consumer countries is insufficient to protect forests and other ecosystems and may worsen deforestation and conversion risks by incentivizing the weakening of social-environmental protection by producer countries.

## 1. The trade of forest-risk commodities

The way we use the land to produce, trade, and consume food is directly connected to social-environmental issues like deforestation, biodiversity loss, human rights violations, climate change, and pandemics (Laroche *et al* 2020, Brancalion *et al* 2020, Curtis *et al* 2018). The production of agricultural commodities is a key driver of deforestation across the globe (Curtis *et al* 2018). However, deforestation embedded in global supply chains is especially acute in the trade routes between commodity-producing countries in the Global South and commodity-importing countries in the Global North. Recognizing their roles as importers and consumer countries, the United Kingdom and the European Union are considering policy measures to address imported deforestation (Bager *et al* 2021). In the context of distant connections in food supply chains (Laroche *et al* 2020), it is crucial to account for GHG emissions, biodiversity loss, and traditional communities' rights embedded in food imports, taking appropriate mitigation measures.

Over the last decade, a wave of voluntary commitments from the private sector and nations (e.g., the Consumer Goods Forum or via the Amsterdam Declarations Partnership) have fallen short in making progress towards deforestation-free supply chains (Garrett *et al* 2019). Hence, at present, there is growing momentum for bolder actions from both government and private companies. Many discussions are in place on what policies could most efficiently halt the environmental degradation driven by agricultural imports (Bager *et al* 2021). Part of this debate favors mandatory due diligence by importing countries to verify compliance with legal criteria from exporting countries (Bager *et al* 2021, Kehoe *et al* 2020). It is essential to highlight that any legislation to tackle deforestation via a legality-based approach is dependent on the efficacy of local governments and legislation and, ultimately, its alignment with downstream deforestation-free objectives.

Considering Brazil as an example of a key agricultural exporter; the country produced around 118 million tons of soybeans in 2018 alone, representing 36% of global soy production (FAO 2021).

57% of Brazil's production in 2018 was exported to China and 11% to Europe, including the UK (Trase 2021). The soy-deforestation risk of this Brazilian soy, which includes deforestation and native vegetation loss in the previous five years that became soy up to 2018, was about 61.4 thousand hectares, emitting slightly over 10 million tons of $CO_2$ (Trase 2021). About 6.3 thousand hectares of this native vegetation loss (~10%) and ~1.1 million tons of emitted $CO_2$ (~11%) belong to the EU, including the UK. These volumes refer only to 2018 soybean production, with impacts even higher in previous years (Trase 2021).

Despite global climate and biodiversity crises, Brazil's current environmental legislation authorizes significant amounts of vegetation loss (Rajão *et al* 2020). This destruction is not necessary from a land-resource standpoint. Brazil has sufficient suitable lands for expanding production without clearing additional hectares of native vegetation (Strassburg *et al* 2014). Moreover, deforestation jeopardizes overall agricultural production and income due to disruptions in local rainfall patterns driven by deforestation (Leite-Filho *et al* 2021). Not even the existing legal requirements are adequately enforced. Roughly 20% of Brazil's soy and at least 17% of beef exports to the EU, produced on the Amazon and Cerrado biomes, may be contaminated by illegal deforestation (Rajão *et al* 2020). Previous studies have shown the limits of Brazil's legislation to tackle illegal deforestation (Azevedo *et al* 2017), and the actual and potential increases in deforestation stemming from bailouts and revisions in the Forest Code (Albuquerque Sant'Anna and Costa 2021, Freitas *et al* 2018b, Sparovek *et al* 2012).

## 2. Natural habitat at high risk of legal deforestation

Here we build upon and go beyond Rajao et al.'s (2020) study. We estimate the potential legal deforestation and carbon emissions in Brazil that may take place shortly (until 2025). For this, we combine several spatially explicit databases and a spatial model that estimates the probability that

78 native vegetation will remain until 2025 in the face of several drivers of land use change (*See*
79 *Methods*).

80 We identify 1,114,693 rural establishments holding ~69.2 million hectares of unprotected native
81 vegetation (*i.e.*, that can be legally deforested), storing ~5.8 billion tons of $CO_2$ (Tables 1 and S1).
82 Out of these, ~3.25 million hectares storing ~152.8 million tons of $CO_2$ are at high risk of
83 deforestation and native vegetation conversion until 2025. Another ~26.8 Mha storing 1.1 billion
84 tons of $CO_2$ are at medium risk (Tables 1, S1, Figures 1, S1, and S2). This is a plausible extent of
85 short-term future deforestation risk. In 2020 alone, Brazil's Amazon and Cerrado biomes together
86 lost 1.8 Mha (PRODES-INPE 2021), with about 70% of this occurring in private lands according to
87 our own estimates based on the properties map of (Freitas *et al* 2018a).

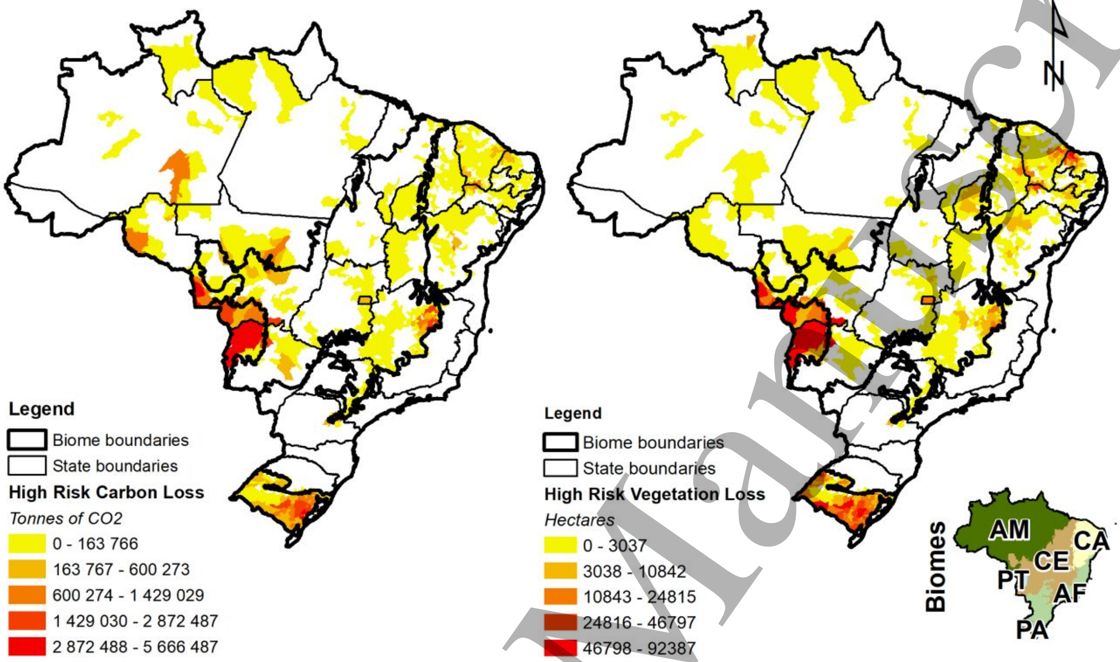
88 Table 1 – Native vegetation and potential carbon dioxide stocks that can be legally cleared and emitted in Brazil until
89 2025.

| Risk of Loss | Number of Rural Establishments | Unprotected Native Vegetation (ha) | Unprotected Carbon (tonnes of $CO_2$) |
|---|---|---|---|
| **1 High Risk** | 104,145 | 3,251,961 | 152,816,882 |
| **2 Medium Risk** | 464,162 | 26,777,911 | 1,107,194,477 |
| **3 Low Risk** | 319,808 | 29,037,483 | 3,796,246,697 |
| **4 No Risk** | 226,578 | 10,186,942 | 782,194,659 |
| **Total** | 1,114,693 | 69,254,298 | 5,838,452,715 |

90

Figure 1 – Maps showing the largest $CO_2$ stocks (in tonnes) and native vegetation areas (in ha) at high risk of legal conversion in Brazil until 2025.

All areas coloured here are municipalities holding areas at high risk of legal conversion. The gradient from yellow to red indicates hectares of potential vegetation loss and tonnes of potential $CO_2$ emissions grouped by municipalities. Pantanal and Pampa biomes appear with the highest risk because these biomes are (i) relatively less protected by public protected areas, such as conservation parks and indigenous lands, (ii) have relatively more private properties than the Amazon, for example, (iii) the Forest Code's mandate for Legal Reserves is smaller in these biomes, setting only 20% of the properties' area aside for conservation. Therefore, 80% of properties' areas are open for legal deforestation. Finally, these areas are closer to agriculturally consolidated regions, near roads and commodity infrastructure and have favourable edaphoclimatic conditions for agricultural commodities cultivation, as considered by Fendrich et al (2020)'s model.



## 3. The legal basis of deforestation in Brazil

The legislative framework built to protect native vegetation in Brazil comprises two main instruments: protected areas in public lands and mandatory conservation in private properties. Protected areas include conservation units – such as national parks and forests – and traditional peoples lands – such as indigenous communities. On the other hand, mandatory protection in private property is mainly regulated by the Forest Code, introduced in 1934 and most recently revised in 2012. The Brazilian Forest Code, unlike most European forest laws, was designed within the paradigm of an open agricultural frontier, granting rural owners the subjective right to convert forest land into agricultural areas as long as certain limits are respected (Rajao *et al* 2021, de Toledo *et al* 2017). These limits are legally defined as Permanent Preservation Areas (natural vegetation in riverbanks, for instance, PPAs) and Legal Reserve (LR), a portion of a given property set aside for conservation or sustainable management (Rajão *et al* 2020, Sparovek *et al* 2012).

In the forestlands of the Amazon biome, as a general rule, 80% of any medium-to-large private property is overall considered Legal Reserve (LR). However, this general rule has exceptions since special conditions allow Amazon states and municipalities to reduce this LR area to 50% (Freitas et al 2018b), and medium to large farmers who cleared up to 50% of their forestlands prior to 2001, when the Legal Reserve was effectively increased from 50 to 80% in the Amazon forestlands, are allowed to have only 50% LRs. Small holders who cleared any amount of LR up to July 2008 have been granted amnesty, therefore not needing to restore these parts (Stickler *et al* 2013). This level of protection is often used as an example of ambitious legislation, but it also means that 20-50% of these medium-to-large properties can be lawfully deforested. Considering that properties in the Amazon can be as large as 20-thousand hectares, the areas open for legal deforestation according to Brazilian law are far from insignificant. Additionally, elsewhere in Brazil, the Legal Reserve areas range from 20% to 35% in equally important biomes such as the Cerrado savanna and the Pantanal wetlands. The Atlantic Forest is an exception because the *Mata Atlântica* protection law forbids any additional clearing. Therefore any deforestation within this biome is undeniably illegal. These biomes are critical carbon sinks. Their conservation is crucial for tackling climate change and the $CO_2$ emissions driven by land use change (Rajão *et al* 2020).

All in all, the 2012 version of the Forest Code defines at least ~101 Mha of Brazil's biomes as areas open for legal deforestation (Freitas *et al* 2018a). This area is about four times the territory of the United Kingdom. The clear-cut of such regions would mean extra emissions of at least 12.48 billion tons of $CO_2$ – all of which potentially authorized by the current Brazilian legislation (Freitas *et al* 2018a). This amount is almost 34 times the UK's total greenhouse gas (GHG) emissions in 2018 alone (UCS 2020). In alignment with our short-term modelled estimates (*See Methods*), this area is what we consider as the *total* amount of possible legal deforestation. Whilst not all of this is likely to be cleared in the near term due to political, biophysical, and infrastructural constraints for deforestation, some areas in Brazil are likely to be at particularly high risk (Figure 1).

## 4. Changing legislation over time

As stated above, Brazil's legislation is permissive enough to allow for a substantial amount of legal $CO_2$ emissions via land use change. Yet, the legal framework to protect native vegetation has been changing in the recent years to allow more legal deforestation and legalize economic activities carried out in former forests and natural habitat that was illegally cleared. The 2012 Forest Code is a stark example of this situation (Sparovek *et al* 2012). From the 1990s, Brazilian environmental agencies ensured that law enforcement was more stringent than before, and thousands of non-compliant rural producers were fined. This generated political pressure to revise the law, passed in 2012, with several amnesties for illegal deforestation carried out before 2008 (Albuquerque Sant'Anna and Costa 2021), thus effectively legalizing previously illegal deforestation. With the changes in 2012 alone, about 41 Mha of deforested and converted lands that should otherwise have been restored to native habitat were granted amnesty (Freitas *et al* 2017). Another ~1 Mha is estimated to have been deforested between 2012 and 2017 due to the incentives provided by the revisions to law (Albuquerque Sant'Anna and Costa 2021).

The Forest Code is not an isolated case. Several bills in Parliament are on the verge of being approved that are likely to bring more amnesties and open additional space for legal deforestation (*See the SI, List of Brazilian Congress Bills*). These bills are part of an overarching movement by the current Bolsonaro administration to re-shape the socio-environmental legal framework in Brazil, incentivizing further legal destruction of natural habitat and carbon emissions and the legalization of agricultural activities that are currently unlawful.

This social-environmental legal laxation movement by the current administration, however, does not sit in isolation. Within local political constituencies ,pro-development and anti-environmental groups are important supporters of the current government and were determinant forces in the election of Bolsonaro for presidency in 2018 (Raftopoulos and Morley 2020, Russo Lopes and Bastos Lima 2020). They are also influential in elections at local levels, mainly in municipalities and states (Rodrigues-Filho *et al* 2015, Pailler 2018), and are likely to substantially influence the next presidential elections in 2022.

## 5. Ways Forward

To effectively implement a legality-based sustainability policy, legal deforestation activity should be monitored by producer-country authorities and by the supply chain itself. In ideal circumstances, Brazilian-based tier-1 companies (i.e. sourcing directly from farmers) would be able to conduct basic verification of their suppliers (i.e. farmers), as they do in arrangements such as the Amazon Soy Moratorium (Austin *et al* 2021, Heilmayr *et al* 2020), cattle agreements (Gibbs *et al* 2015), or the High Carbon Stock Approach (Austin *et al* 2021). However, this verification capacity would not be directly possible for tier-2 or tier-3 companies (e.g. importers, processors and retailers), obliged to meet the incoming United Kingdom's due diligence legislation to place materials on the UK market, since they do not purchase directly from farmers, but from tier-1 companies. Another example of basic verification, in Brazil, is the Federal Environmental Enforcement Agency (IBAMA)'s list of embargoed areas. This list indicates areas that have been illegally cleared. When detected, these areas are embargoed to promote the restoration or regeneration of native vegetation. Nothing can be produced or traded from these areas. Therefore, a basic verification step to be carried out by companies is checking whether their supplying farmers are on that list.

Second, companies can undertake supply chain engagement with upstream suppliers (Austin *et al* 2021), and request the documentation attesting the legality of production. In Brazil's example, a farmer can only conduct deforestation if they hold an Authorization for Native Vegetation Suppression (ASV, in Brazilian Portuguese acronym), which is issued by state authorities. Therefore, downstream companies might detect deforestation on a supplying-farm by remote sensing and request the presentation of this permit as proof of legality. Importantly, the existence of this permit system implies that achieving zero-illegal deforestation or native vegetation conversion relies substantially on the discretion of the domestic legislation of producer-countries. The robustness of the domestic legislation is therefore worthy of additional attention".

In the case of Brazil, for example, to be considered legal, any land use change from native vegetation to agricultural cover in Brazil must be subject to approval by the State Environmental Department before it takes place. The State Environmental Department must assess cases and issue land clearing permits if the requests comply with all legal requirements. Authorizations must identify the geospatial location of the clearance. Nevertheless, most states in Brazil lack any tracking system for these authorizations, which means there is effectively no monitoring of whether the authorized deforestation is being carried out lawfully. Currently, Brazilian agencies lack the technical capacity and political willingness to monitor, verify, enforce and report land use regulation.

Without such local information (i.e., the ASVs), and in the context of the global supply chains in which soy is embedded, it is virtually impossible to attest if deforestation has been carried out legally or not (Valdiones *et al* 2021). Companies point out technical difficulties in monitoring and verifying legal deforestation to challenge regulation and enforcement by consumer countries (Lambin *et al* 2020). An ideal scenario would be one where buyers could request the legal permits of clearings and production operations from their upstream suppliers (*i.e.,* farmers). However, this is complicated by technical issues related to Brazilian authorities' incapacity or unwillingness to monitor, verify, enforce, and report legal compliance.

There are several methods to trace and verify *gross* (i.e. rather than just legal) zero-deforestation and natural habitat conversion in export supply chains at the jurisdictional level of production (Lathuillière *et al* 2021, Green *et al* 2019, Escobar *et al* 2020, Austin *et al* 2021). Platforms such as Trase (Trase 2021) and Mapbiomas (Mapbiomas 2021) are examples of publicly available supply chain and land use data that companies can use for risk assessments. These tools do not yet show deforestation at the individual farm-level in the case of Brazil. This level of detail would, for example, require integration with official government data, such as with the Rural-Environmental Registry (CAR, in the Brazilian-Portuguese acronym), and the ASV state spatial datasets but these datasets are still pending validation and not publicly available in all states (Valdiones *et al* 2021). Despite the limitations of publicly available data that links supply chain activities to *gross* clearance, it is arguably the case that – due to concerns about local monitoring and enforcement necessarily to demonstrate legality - downstream companies can assess risk exposure to gross deforestation at least as easily as to illegal deforestation.

Ultimately, companies can – and do – have mechanisms to audit and verify whether their supply chains are deforestation-free via supplier engagement processes, such as voluntary certification schemes such as the Roundtable on Sustainable Soy (RTRS) and the Forest Stewardship Council (FSC). However, a missing link to ensure a level playing field and promote industry-wide action is mandatory regulation that applies to all companies for all forest-risk commodities, with requirements for precise cut-off dates, past, present, or future, to mark when no conversion will be allowed in supply chains (Garrett *et al* 2019). These certification tools can, therefore, be important learning and information experiences to construct new mandatory systems.

Since companies and supply chain actors have been failing to define commitments and cut-off dates voluntarily (Garrett *et al* 2019), clear and stringent mandatory regulation demanding zero gross deforestation and natural habitat conversion by consumer-country authorities appears to be an effective measure. While the introduction of downstream legislation covering all forms of deforestation may appear politically infeasible in the short term (Bager *et al* 2021), it should not be dismissed as an ultimate goal. Nor should other potential policy mechanisms which have the potential to encompass broader protections be de-prioritized.

In sum, in addition to being insufficient to prevent deforestation activity in all forms, regulation based solely on the criterion of legality carries the risk that it may be detrimental to the protection of forests. In countries where legislation can be easily modified, as is demonstrably the case for Brazil, increased demand for products with legal origins can increase pressure for legislative changes that aim to legalize agricultural activities located in illegally deforested areas. These legislative changes, in turn, also pave the way for more legal deforestation. Therefore, while welcoming the steps made by governments to introduce regulation to respond to the global threat of deforestation, we urge consumer-nation policymakers to consider zero-*gross* deforestation and zero native vegetation conversion criteria in their initiatives to address imported deforestation, GHG emissions, and biodiversity loss, considering that this is technically viable and potentially effective despite the short-term political hurdles that would need to be overcome to implement these advanced measures.

## 6. Methods and Data

First, we use a property-level boundaries spatial dataset, which includes the amounts of Legal Reserves (LR), Permanent Preservation Areas (PPAs), and the surplus of LRs (i.e., that can be legally cleared) (Freitas *et al* 2018a). Second, we use an aboveground carbon density map at 50m pixel resolution for Brazil (Englund *et al* 2017). Third, we use spatial projections of unprotected native vegetation in private lands, considering rural establishments that can conduct legal clearings (Freitas *et al* 2018a). Fourth, we employ a spatially-explicit modelling approach that estimates the probability of the existence of native vegetation until 2025 (Fendrich *et al* 2020). This model considers topography, soil properties, climate data, distance to transportation corridors, and legally protected areas, including indigenous lands. This unprecedented combination of spatial datasets allows us to estimate the potential future legal deforestation with different levels of risk. For the purpose of alignment with climate policy, we use the 44/12 conversion factor to estimate the potential carbon dioxide ($CO_2$) emissions based on the total carbon stocks in the areas at risk of legal deforestation (Federici *et al* 2015). Therefore, we report the results directly in potential $CO_2$ emissions.

We adopt a conservative approach, excluding from this analysis the areas that Freitas et al. (2018a) projected as potential private properties to fill spatial gaps in the Brazilian territory. We only consider the rural establishments officially registered and identified at Brazilian land databases. Therefore, while Freitas et al. (2018a) estimated ~101 Mha of unprotected native vegetation within private lands, we only considered ~69.2 Mha. We use Fendrich et al.'s (2020)(Fendrich *et al* 2020) land cover model to classify these unprotected areas according to their risk of conversion.

The land tenure database presented in Freitas et al. (2018) (Freitas *et al* 2018a) and updated by Freitas et al. (2018) (Freitas *et al* 2018b) was used as starting point for the analysis presented here. This database comprises public and private properties in Brazil such as Indigenous Lands, Conservation Units, Quilombola Territories, and private rural properties from the Rural Environmental Registry (Portuguese acronym CAR) and the georeferenced properties of the National

Agrarian Reform Institute (Portuguese acronym SIGEF). The database also includes information on the compliance of these rural properties with the Brazilian Forest Code. It has information related to the area of native vegetation and the amount of aboveground carbon stock within each rural property (Freitas *et al* 2018a, Englund *et al* 2017). With the existent variables, it is also possible to identify the part of the native vegetation (or its carbon stocks) that is both legally protected or has the potential to be legally deforested (the latter called hereafter as unprotected native vegetation or unprotected carbon stocks).

Fendrich et al. (2020) (Fendrich *et al* 2020) presented maps of the probability of the existence of native vegetation in a given pixel for the years 2017 and 2025. The probabilities are calculated based on a spatially explicit regression model that explores the relation of land cover maps of the Mapbiomas project (2019)(Mapbiomas 2021) and spatial variables (drivers of land cover change), such as topography, soil properties, climate data, distance to transportation corridors and legally protected areas, including indigenous lands. The land cover maps were reclassified to four classes in the model, namely, native vegetation, pasture, agriculture, and other uses. The existence of these four land cover classes was analyzed for every pixel in the entire period (from 1985 to 2017). The model captured the relation of the land cover classes and the spatial variables. Based on alternative future climate and policy scenarios (S1 - aggressive, S2 - business as usual, and S3 - conservative scenarios), Fendrich et al. (Fendrich *et al* 2020) estimated the probability of the existence of native vegetation, agriculture, and pasture in Brazil for the year 2025.

The Fendrich et al. (2020)'s scenarios are based on the following. The S1 scenario, aggressive, considers no mitigation policy and additional environmental protection is adopted in Brazil. Furthermore, transport and energy national expansion plans are fully implemented, the population and the economy grows untapped according to national projections. The S2, business as usual, considers some environmental policies and decisions are implemented in Brazil, competing with economic growth. The S3, conservative, assumes that in Brazil there are large-scale and active

296 restoration of native vegetation and significant improvements in environmental policies (Fendrich *et*
297 *al* 2020).

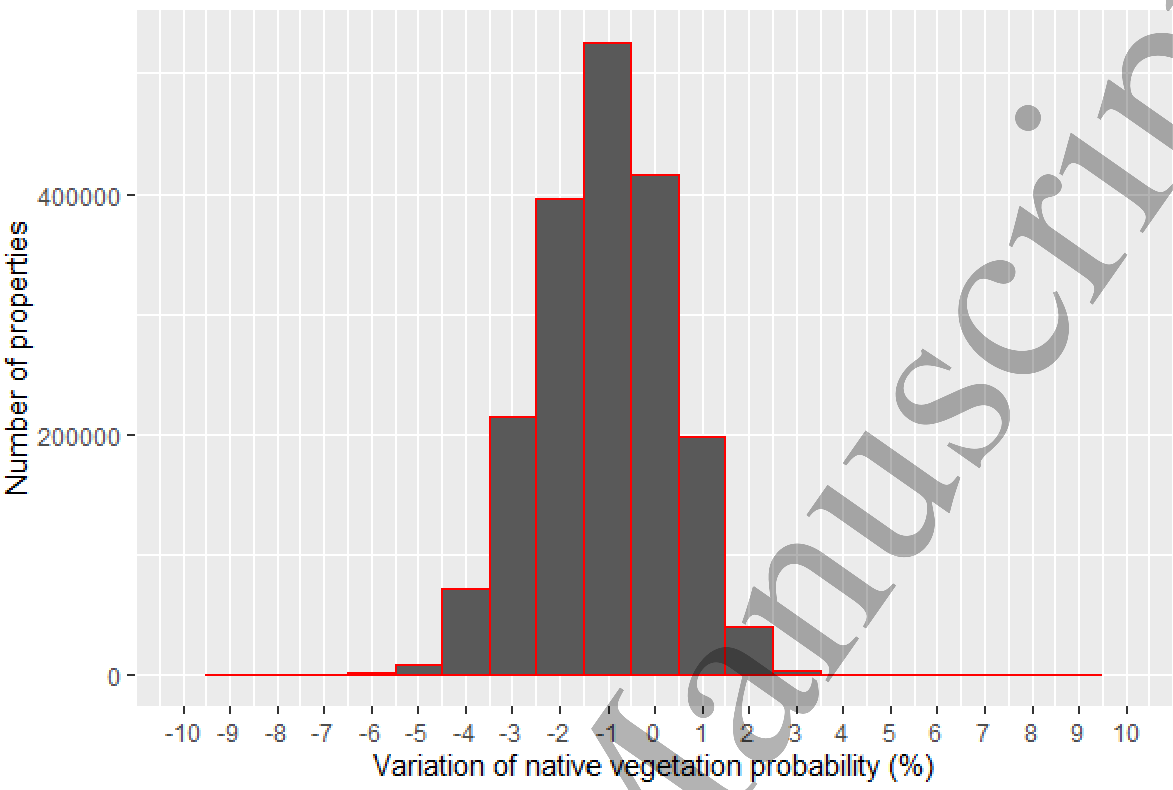
298 Here we used the S2 - business as usual scenario, to generate a map of the variation of native
299 vegetation probability (VNVP map) between 2017 and 2025, where positive values represent pixels
300 with an increase in the probability of native vegetation existence until 2025. In contrast, negative
301 values represent pixels with a decrease in the probability of native vegetation existence until 2025.
302 Further, we have combined the rural properties with unprotected native vegetation and the VNVP
303 map to extract the average probability for each of these properties. These probability values are
304 relative and averaged over all pixels per property. Therefore, this value presents the average
305 probability of natural vegetation occurring on properties with Legal Reserve surpluses being lost. For
306 example, if the Legal Reserve surplus of a property is composed equally by pixels with VNVP of 2%
307 and 5%, then its average VNVP is 3.5%, therefore it has not risk of being lost until 2025. If the value
308 is negative, then there is risk of legal deforestation. Fig. S1 expresses the distribution of the average
309 probabilities within rural properties.

310 The distribution of the VNVP shows that 99.6% of the properties with unprotected native
311 vegetation have VNVP between -5% and +5%, with the majority of the properties (79,2 % of the
312 total) presenting negative values (Fig. 2). Based on the distribution of the VNVP, we defined four
313 classes of risk of the deforestation of unprotected native vegetation:

314 - Properties with VNVP lower than -3% = High risk
315 - Properties with VNVP between -3% and -1%= Medium risk
316 - Properties with VNVP between -1% and 0% = Low risk
317 - Properties with VNVP higher or equal than 0% = No risk

318

Fig. 2 - Distribution of the average variation of native vegetation probability (VNVP) between 2017 and 2025 within rural properties with unprotected native vegetation. Positive values represent pixels with increase in the probability of native vegetation existence until 2025 whereas negative values represent pixels with decrease in the probability of native vegetation existence until 2025.



**References**


Albuquerque Sant'Anna A and Costa L 2021 Environmental regulation and bail outs under weak state capacity: Deforestation in the Brazilian Amazon *Ecol. Econ.* **186** 107071 Online: https://linkinghub.elsevier.com/retrieve/pii/S0921800921001294

Austin K G, Heilmayr R, Benedict J J, Burns D N, Eggen M, Grantham H, Greenbury A, Hill J K, Jenkins C N, Luskin M S, Manurung T, Rasmussen L V, Rosoman G, Rudorff B, Satar M, Smith C and Carlson K M 2021 Mapping and Monitoring Zero-Deforestation Commitments *Bioscience* **71** 1079–90 Online: https://academic.oup.com/bioscience/article/71/10/1079/6348368

Azevedo A A, Rajão R, Costa M A, Stabile M C C, Macedo M N, dos Reis T N P, Alencar A, Soares-Filho B S and Pacheco R 2017 Limits of Brazil's Forest Code as a means to end illegal deforestation *Proc. Natl. Acad. Sci.* **114** 7653–8 Online: http://www.pnas.org/lookup/doi/10.1073/pnas.1604768114

Bager S L, Persson U M and dos Reis T N P 2021 Eighty-six EU policy options for reducing imported deforestation *One Earth* **4** 289–306 Online: https://doi.org/10.1016/j.oneear.2021.01.011

Brancalion P H S, Broadbent E N, De-Miguel S, Cardil A, Rosa M R, Almeida C T, Almeida D R A, Chakravarty S, Zhou M, Gamarra J G P, Liang J, Crouzeilles R, Hérault B, Aragão L E O C, Silva C A and Almeyda-Zambrano A M 2020 Emerging threats linking tropical deforestation and the COVID-19 pandemic *Perspect. Ecol. Conserv.* **18** 243–6 Online: https://linkinghub.elsevier.com/retrieve/pii/S2530064420300584

Curtis P G, Slay C M, Harris N L, Tyukavina A and Hansen M C 2018 Classifying drivers of global forest loss *Science (80-. ).* **361** 1108–11 Online: http://www.sciencemag.org/lookup/doi/10.1126/science.aau3445

Englund O, Sparovek G, Berndes G, Freitas F, Ometto J P, Oliveira P V D C E, Costa C and Lapola D 2017 A new high-resolution nationwide aboveground carbon map for Brazil *Geo Geogr. Environ.* **4** e00045 Online: http://doi.wiley.com/10.1002/geo2.45

Escobar N, Tizado E J, zu Ermgassen E K H J, Löfgren P, Börner J and Godar J 2020 Spatially-explicit footprints of agricultural commodities: Mapping carbon emissions embodied in Brazil's soy exports *Glob. Environ. Chang.* **62** 102067 Online: https://doi.org/10.1016/j.gloenvcha.2020.102067

FAO 2021 FAOSTAT - Food and Agriculture Organization. Crop statistics database. Online: http://www.fao.org/faostat/en/#data/QC/

Federici S, Tubiello F N, Salvatore M, Jacobs H and Schmidhuber J 2015 New estimates of CO2 forest emissions and removals: 1990–2015 *For. Ecol. Manage.* **352** 89–98 Online: http://dx.doi.org/10.1016/j.foreco.2015.04.022

Fendrich A N, Barretto A, de Faria V G, de Bastiani F, Tenneson K, Guedes Pinto L F and Sparovek G 2020 Disclosing contrasting scenarios for future land cover in Brazil: Results from a high-resolution spatiotemporal model *Sci. Total Environ.* **742** 140477 Online: https://doi.org/10.1016/j.scitotenv.2020.140477

Freitas F L M de, Sparovek G, Mörtberg U, Silveira S, Klug I and Berndes G 2017 Offsetting legal deficits of native vegetation among Brazilian landholders: Effects on nature protection and socioeconomic development *Land use policy* **68** 189–99 Online: https://linkinghub.elsevier.com/retrieve/pii/S0264837716310997

Freitas F L M M, Englund O, Sparovek G, Berndes G, Guidotti V, Pinto L F G G and Mörtberg U 2018a Who owns the Brazilian carbon? *Glob. Chang. Biol.* **24** 2129–42 Online: http://doi.wiley.com/10.1111/gcb.14011

Freitas F L M, Sparovek G, Berndes G, Persson U M, Englund O, Barretto A and Mörtberg U 2018b Potential increase of legal deforestation in Brazilian Amazon after Forest Act revision *Nat. Sustain.* **1** 665–70 Online: http://dx.doi.org/10.1038/s41893-018-0171-4

Garrett R D, Levy S, Carlson K M, Gardner T A, Godar J, Clapp J, Dauvergne P, Heilmayr R, le Polain de Waroux Y, Ayre B, Barr R, Døvre B, Gibbs H K, Hall S, Lake S, Milder J C, Rausch L L, Rivero R, Rueda X, Sarsfield R, Soares-Filho B and Villoria N 2019 Criteria for effective zero-deforestation commitments *Glob. Environ. Chang.* **54** 135–47 Online: https://linkinghub.elsevier.com/retrieve/pii/S0959378018306654

Gibbs H K, Munger J, L'Roe J, Barreto P, Pereira R, Christie M, Amaral T and Walker N F 2015 Did Ranchers and Slaughterhouses Respond to Zero-Deforestation Agreements in the Brazilian Amazon? *Conserv. Lett.* **0** n/a-n/a Online: http://doi.wiley.com/10.1111/conl.12175

Green J M H, Croft S A, Durán A P, Balmford A P, Burgess N D, Fick S, Gardner T A, Godar J, Suavet C, Virah-Sawmy M, Young L E and West C D 2019 Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity *Proc. Natl. Acad. Sci.* **116** 23202–8 Online: http://www.pnas.org/lookup/doi/10.1073/pnas.1905618116

Heilmayr R, Rausch L L, Munger J and Gibbs H K 2020 Brazil's Amazon Soy Moratorium reduced deforestation *Nat. Food* **1** 801–10 Online: http://dx.doi.org/10.1038/s43016-020-00194-5

Kehoe L, Reis T N P, Meyfroidt P, Bager S, Seppelt R, Kuemmerle T, Berenguer E, Clark M, Davis K F, Ermgassen E K H J, Farrell K N, Friis C, Haberl H, Kastner T, Murtough K L, Persson U M, Connell C O, Valeska V and Romero-mun A 2020 Inclusion, Transparency, and Enforcement: How the EU-Mercosur Trade Agreement Fails the Sustainability Test - Commentary *One Earth* Online: https://www.cell.com/one-earth/fulltext/S2590-3322(20)30422-X

Lambin E F, Kim H, Leape J and Lee K 2020 Scaling up Solutions for a Sustainability Transition *One Earth* **3** 89–96 Online: https://doi.org/10.1016/j.oneear.2020.06.010

Laroche P C S J, Schulp C J E, Kastner T and Verburg P H 2020 Telecoupled environmental impacts of current and alternative Western diets *Glob. Environ. Chang.* **62** 102066 Online: https://doi.org/10.1016/j.gloenvcha.2020.102066

Lathuillière M J, Patouillard L, Margni M, Ayre B, Löfgren P, Ribeiro V, West C, Gardner T A and Suavet C 2021 A Commodity Supply Mix for More Regionalized Life Cycle Assessments *Environ. Sci. Technol.* acs.est.1c03060 Online: https://pubs.acs.org/doi/10.1021/acs.est.1c03060

Leite-Filho A T, Soares-Filho B S, Davis J L, Abrahão G M and Börner J 2021 Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon *Nat. Commun.* **12** 2591 Online: http://dx.doi.org/10.1038/s41467-021-22840-7

Mapbiomas 2021 Collection v5 of Brazilian Land Cover & Use Map Series 6 Online:

https://plataforma.brasil.mapbiomas.org/

Pailler S 2018 Re-election incentives and deforestation cycles in the Brazilian Amazon *J. Environ. Econ. Manage.* **88** 345–65 Online: http://dx.doi.org/10.1016/j.jeem.2018.01.008

PRODES-INPE 2021 Prodes - Brazilian Deforestation Monitoring Program Online: http://terrabrasilis.dpi.inpe.br/

Raftopoulos M and Morley J 2020 Ecocide in the Amazon: the contested politics of environmental rights in Brazil *Int. J. Hum. Rights* **24** 1616–41 Online: https://doi.org/10.1080/13642987.2020.1746648

Rajão B R, Soares-filho B, Nunes F, Börner J, Machado L, Assis D, Oliveira A, Pinto L, Ribeiro V, Rausch L and Gibbs H 2020 The rotten apples of Brazil's agribusiness *Science (80-. ).* 0–3

Rajao R, Giudice R Del, Van Der Hoff R and Carvalho E B de 2021 *Uma breve história da legislação florestal brasileira* (Rio de Janeiro: Observatório do Código Florestal) Online: https://observatorioflorestal.org.br/wp-content/uploads/2021/05/LIVRO_LEGISLACAO_FLORESTAL.pdf

Rodrigues-Filho S, Verburg R, Bursztyn M, Lindoso D, Debortoli N and Vilhena A M G 2015 Election-driven weakening of deforestation control in the Brazilian Amazon *Land use policy* **43** 111–8 Online: https://linkinghub.elsevier.com/retrieve/pii/S0264837714002439

Russo Lopes G and Bastos Lima M G 2020 Necropolitics in the Jungle: COVID-19 and the Marginalisation of Brazil's Forest Peoples *Bull. Lat. Am. Res.* **39** 92–7 Online: https://onlinelibrary.wiley.com/doi/10.1111/blar.13177

Sparovek G, Berndes G, Barretto A G de O P and Klug I L F 2012 The revision of the Brazilian Forest Act: increased deforestation or a historic step towards balancing agricultural development and nature conservation? *Environ. Sci. Policy* **16** 65–72 Online: https://linkinghub.elsevier.com/retrieve/pii/S1462901111001687

Stickler C M, Nepstad D C, Azevedo A a, McGrath D G and B P T R S 2013 Defending public interests in private lands: compliance, costs and potential environmental consequences of the Brazilian Forest Code in Mato Grosso. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **368** 20120160 Online: http://rstb.royalsocietypublishing.org/content/368/1619/20120160.full

Strassburg B B N, Latawiec A E, Barioni L G, Nobre C a., da Silva V P, Valentim J F, Vianna M and Assad E D 2014 When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil *Glob. Environ. Chang.* **28** 84–97 Online: http://www.sciencedirect.com/science/article/pii/S0959378014001046

de Toledo P M, Dalla-Nora E, Vieira I C G, Aguiar A P D and Araújo R 2017 Development paradigms contributing to the transformation of the Brazilian Amazon: do people matter? *Curr. Opin. Environ. Sustain.* **26–27** 77–83 Online: https://linkinghub.elsevier.com/retrieve/pii/S1877343517300192

Trase 2021 Brazil Soy Data PCS v 2.5.0 Online: https://trase.earth/flows/data-view?toolLayout=1&countries=27&commodities=1&selectedColumnsIds=0_22-1_28-2_37-3_33

UCS 2020 Each Country's Share of CO2 Emissions *Union Concerned Sci.* 2020 Online: https://www.ucsusa.org/resources/each-countrys-share-co2-emissions

451 Valdiones A P, Bernasconi P, Silgueiro V, Guidotti V, Miranda F, Costa J, Rajão R and Manzolli B 2021 *Illegal Deforestation and Conversion in the Amazon and MATOPIBA: lack of transparency and access to information* Online: https://www.icv.org.br/website/wp-content/uploads/2021/05/icv-relatorio-ing-v1-1.pdf

**Funding:**

European Union's Horizon 2020 research and innovation program under Marie Skłodowska-Curie grant agreement no. 765408 COUPLED (TNPR)

The UK Research and Innovation's Global Challenges Research Fund Trade, Development and the Environment Hub project (grant ES/S008160/1) (CW)

Norwegian Agency for Development Cooperation (Norad) (grant QZA-21/0156) (CW)

The Gordon and Betty Moore Foundation (grant 7703.01) (CW)

World Wildlife Fund Brazil (Science Program's and Public Policy's institutional budget) (MNF, RSTV, MMSE, GRL)

Instituto de Manejo e Certificação Florestal (IMAFLORA) (Institutional Budget) (VGF)

Universidade de São Paulo – USP (Institutional Budget) (GS)

Universidade Federal de Minas Gerais (UFMG) (Institutional Budget) (RGR)

**Author contributions:**

Conceptualization: RSTV, TNPR, VGF, GS, MMSE.

Methodology: TNPR, VGF, GS.

Investigation: TNPR, VGF, MMSE.

Visualization: VGF, TNPR, GS.

Funding acquisition: MNF, RSTV, CW, RGR, GS.

Supervision: GS, MNF, RGR, CW.

Writing – original draft: TNPR, GRL, CW, GS, RSTV, MMSE.

Writing – review & editing: TNPR, MNF, RGR, CW, GRL, RSTV.

**Competing interests:** Authors declare that they have no competing interests.