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The Problem of Enforcing Environmental Clauses in the EU–Mercosur Partnership Agreement in the Context of the Discrepancy in Deforestation Indices

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Abstract

The EU–Mercosur Partnership Agreement (EMPA), whose ratification process started following the European Commission's decision on 3 September 2025, is one of the EU's most comprehensive trade agreements. From the outset, it raised serious concerns among environmental organizations about the risk of accelerating deforestation in the Amazon, potentially exacerbated by the liberalization of trade in agricultural products. This article analyzes the problem of enforcing the environmental provisions of the agreement in the context of deforestation. We argue that the effectiveness of these clauses is fundamentally undermined by two interrelated challenges: the limitations of the legal mechanisms enshrined in the agreement and the increasing ambiguity of data used to monitor deforestation. Using statistical analysis of time series (2002–2024)—including Student's *t*-test for dependent samples, Spearman rank correlation, and trend regression models—the nature and trend of increasing divergence between two major indicators of deforestation, namely the official Brazilian PRODES and the Global Forest Watch (GFW), were quantified. The results show a systematic and statistically significant discrepancy between indicators, which has structurally widened since 2015. This fundamental ambiguity of data creates a serious "enforcement gap", allowing us to challenge the scale of the violations and may, in practice, prevent the effective application of the environmental clauses of the agreement, undermining the EU's policy objectives related to the EUDR and the Green Deal. The article also outlines institutional options to address this enforcement gap by strengthening the transparency, consistency, and evidentiary use of deforestation data in the implementation of the agreement.

Keywords: PRODES; GFW; environmental clauses; deforestation; trade agreement; EU–Mercosur agreement; indicator analysis

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Academic Editors: Karlo Beljan and Andres I. Susaeta

Received: 9 November 2025
Revised: 24 November 2025
Accepted: 3 December 2025
Published: 5 December 2025

Citation: Olech, I.; Krupska, K.; Kosior, K. The Problem of Enforcing Environmental Clauses in the EU–Mercosur Partnership Agreement in the Context of the Discrepancy in Deforestation Indices. *Forests* **2025**, *16*, 1821. https://doi.org/10.3390/f16121821

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1. Introduction

The European Union (EU) and Mercosur are the largest integration blocs in their regions, which connect countries with a high degree of economic interconnection. They were created to significantly reduce or remove trade barriers within them [1]. Negotiations on the partnership between these two economic organizations began as early as 1999, but were suspended for many years, among others due to the protests of the EU agricultural producers, who feared a decrease in the competitiveness of their products and the influx of cheaper, and at the same time worse quality food, which would not meet the high

quality standards of the EU, with which they were obliged to comply [2]. At the same time, environmental organizations have pointed out that trade liberalization may lead to an increase in deforestation in the Amazon region, especially in regions already affected by agricultural pressure and the progressive expansion of commodity crops [3]. An analysis of the regulations of the previous version of the agreement, which was created after a political agreement between the two blocs was reached in 2019 and carried out in 2020, indicated that the environmental protection mechanisms included in the EU–Mercosur Partnership Agreement were ineffective [4].

Given the scale of the trade in goods to date and the strategic importance of the EU and South American markets for their partners, the move towards a partnership agreement seems to be a natural consequence of trade between the EU and Mercosur, which involves large volumes of goods and services. The value of the EU's investments in Mercosur in 2022 amounted to EUR 384.7 billion, while the value of trade between the two economic organizations reached over EUR 111 billion, with EUR 55.2 billion being exports and EUR 56 billion being imports. Importantly, more than 80% of trade flows took place between the EU and Brazil, which suggests that the agreement would particularly deepen this country's trade with the EU. It can be noted that between 2014 and 2024, trade in goods between the EU and Mercosur increased by more than 36%, with imports increasing by more than 50% and exports by 25% [5]. According to the report, the most important goods imported by the EU are agricultural products, mineral products, and paper pulp and paper [5]. Undoubtedly, they are linked to the pressure on natural resources, including, above all, the problem of deforestation and environmental degradation in the Mercosur countries. For countries such as Argentina or Brazil, the abolition of tariffs would mean, for example, more favorable sales conditions for agricultural goods such as beef [6].

Doubts about the agreement are exacerbated by the fact that in the case of Mercosur countries, internal liberalization is relatively small compared to the external reforms carried out by the bloc's participants [1]. This means that this integration is mainly focused on cooperation, not internally, as is the case with the EU, but with other economic blocs. In addition, it should be noted that while this cooperation was undertaken due to the prospect of mutual benefit, some studies point to a possible asymmetry in relations between the two blocs and the potentially significant impact of the EU on the institutional shaping of Mercosur [7–9], the asymmetry of the benefits of trade [10], and certainly the differences in the priorities of the two blocs [11], especially in the context of agricultural trade, and thus labor law, or environmental protection [6,12]. Other researchers point out that these differences may reveal the ineffectiveness of the EU's "soft power" in shaping the institutional governance of Mercosur countries [11,13]. Thus, while highlighting the benefits of the free trade agreement, research also highlights the potential reasons for disputes arising from compliance with regulations or access to markets [14,15].

Despite the lack of unity on the EU's cooperation with Mercosur, on 3 September 2025, the European Commission adopted proposals for a Council decision on the signing and conclusion of the EU–Mercosur Partnership Agreement (EMPA) and the Interim Trade Agreement (ITA). The EMPA contains general information on cooperation between the parties, policies, and trade, while the Interim Trade Agreement (ITA) covers only trade issues between the parties and, as its name suggests, is intended to be temporary, pending the entry into force of the EU–Mercosur Partnership Agreement. The presentation of the text of the EU–Mercosur Partnership Agreement has initiated the process of its ratification.

The adoption of the agreement coincides with the intensification of efforts to protect forests and climate in the EU, developed under the European Green Deal and the EUDR regulation. This new legal regime places a fundamental emphasis not only on sustainability declarations, but on their hard enforceability, based on a system of due diligence and verifi-

able data. In this article, we use the term "enforcement gap" to describe situations in which environmental obligations are formally in place but cannot be effectively operationalised or invoked in practice because the underlying empirical indicators are structurally divergent or contested. In this context, the effectiveness of the ambitious environmental clauses in the EU–Mercosur agreement becomes inextricably linked to the methodological question of how deforestation is measured and reported. Major discrepancies in measurement data thus risk opening such an enforcement gap, weakening the environmental pillar of the contract and fuelling commercial and legal disputes [16].

In light of the above, the deforestation question is analysed twofold. First, the article analyses the *de iure* legal mechanisms included in the agreement for the protection of forests. Second, in a key empirical section, the paper examines the *de facto* fundamental challenge to the enforcement of these mechanisms, which is the increasing statistical divergence between the two studied indicators of deforestation: PRODES and the Global Forest Watch (GFW). This analysis provides an answer to the question of whether the EU's ambitious environmental goals are achievable in the face of both the weaknesses of the legal mechanisms enshrined in the text of the agreement and the fundamental ambiguity of the data used to monitor deforestation. This article contributes in three main ways. First, it offers a systematic, quantitative comparison of the PRODES and GFW deforestation indicators for the Brazilian Amazon over the 2002–2024 period, including an exploration of potential structural changes around 2015. Second, it introduces the notion of an "enforcement gap" that can arise when international environmental obligations are linked to empirical indicators that diverge structurally. Third, it connects this indicator divergence to the legal design and enforcement of the EU–Mercosur Agreement and the EUDR due diligence framework, highlighting its implications for monitoring, evidentiary standards, and dispute settlement, and pointing to the need for more robust, multi-source evidentiary arrangements. More broadly, the EMPA forms part of a wider trend in which the EU includes Trade and Sustainable Development (TSD) chapters in its preferential trade agreements. Experience with agreements such as the EU–Korea FTA or the EU–Peru/Colombia FTA shows that, although they establish committees, civil-society mechanisms, and panel-of-experts procedures, the enforcement of environmental provisions has so far been limited and often contested [17–19]. Against this background, the EMPA appears particularly vulnerable to measurement ambiguity, because its forest-related obligations interact directly with deforestation indicators whose levels and even trends differ substantially across datasets.

2. Environmental Safeguards to Prevent Deforestation in the EU–Mercosur Partnership Agreement (EMPA and ITA)

The trade agreement between the EU and Mercosur undoubtedly has potential for economic development, but it also poses a significant environmental challenge, including the risk of increased deforestation in the Amazon region. Environmental protection issues are very important for the EU, as its overriding ecological goal was to ensure economic growth and a sustainable improvement in the lives of its inhabitants, which at the same time will not lead to the destruction of the natural environment and will allow for the mitigation of the changes caused by production [20]. For many years, regulations have been introduced in the EU to support this goal, and one of the important environmental problems highlighted when discussing the EU–Mercosur Partnership Agreement is the phenomenon of deforestation carried out in order to obtain a larger area of land intended for cultivation or the extraction of natural resources. Deforestation and forest degradation are major contributors to the global climate crisis, exacerbating changes in the carbon cycle, biodiversity loss, and soil degradation [21]. This problem is particularly evident in Brazil and affects, to a large extent, the Amazon rainforest areas.

In response to these threats, the EU–Mercosur Partnership Agreement [22] provides mechanisms to monitor and mitigate the negative impact of economic activities on ecosystems. These are mainly described in Chapter 18 of the proposed agreement, entitled "Trade and Sustainable Development". As indicated in Article 18.1(1), the objective of this chapter is to strengthen sustainable integration in trade and investment between the parties to the agreement.

Relevant climate and trade issues are identified in Article 18.6 of the proposed agreement. Paragraph 1 of that article states that the parties are to pursue the ultimate goal of the United Nations Framework Convention on Climate Change (UNFCCC), signed in New York on 9 May 1992. The next paragraph indicates that each Party to the Agreement has the task of effectively implementing the UNFCCC and the Paris Agreement, including promoting the positive contribution of trade to the transition to a path that is characterized, among other things, by resilience to climate change.

The importance of forest protection in the EU–Mercosur Partnership Agreement [22] is evidenced by the fact that an entire Article 18.8, entitled "Trade and sustainable management of forests", is devoted to it. Paragraph 2 indicates that each party to the agreement is to promote trade in products from sustainably managed forests, harvested in accordance with the laws and regulations of the countries of harvest. In addition, it is also expected to implement measures to combat illegal logging and related trade, and exchange information on sustainable forest management trade-related initiatives. Article 18.13(1)(j) of the Agreement also indicates that the Parties to the Agreement should promote the conservation and sustainable management of forests in order to reduce deforestation and illegal logging [22]. These provisions undoubtedly show that the EU recognises the importance of forests as a key element of global ecological sustainability and a resource of fundamental importance for tackling climate degradation [23].

Analyzing the contractual provisions of the EU–Mercosur Partnership Agreement, it can be seen that they are closely related to international climate commitments, which is beyond doubt, given the priority nature of climate issues in the EU's regulations. Undoubtedly, the Paris Agreement should be considered one of the fundamental pillars of this agreement. The scope of the powers of the parties to the EU–Mercosur Partnership Agreement has been defined in such a way that, in the event of a serious breach of its provisions by one of the Parties, the other obtains, inter alia, the right to suspend the performance of the agreement. The Paris Agreement itself has a significant impact on international trade, as well as on the implementation of the EU–Mercosur Partnership Agreement, as it aims not only to reduce greenhouse gas emissions, but also to tackle illegal deforestation, in particular in the Brazilian Amazon, under the National Determined Contributions (NDCs). In addition, the provisions of the agreement oblige the parties to effectively implement other multilateral environmental agreements, which also include the CITES Convention on Trade in Wild Fauna and Flora.

When discussing the issue of imports of goods from Mercosur countries, goods imported under the agreement will also be subject to EU regulations aimed at restricting the introduction to the EU market and exports from the EU of certain goods and products related to deforestation and forest degradation. These include, among others, the so-called Regulation No. 2023/1115 (otherwise known as the EUDR Regulation) [24], which partially entered into force on 29 June 2023. It constitutes another preventive instrument, autonomous from the provisions of the agreement, but functionally complementary to it. The EUDR Regulation interacts significantly with the provisions of the agreement, as Mercosur countries intending to export their products to the EU market will be required to comply with its provisions [25,26]. It is worth noting, however, that the EUDR uses the term "due diligence", which is a very vague term, of an evaluative nature, and requires

interpretation in the context of the objectives and scope of the Regulation. In EU law, due diligence is a precondition for objectively attributing liability to an entity for failing to act in accordance with an obligation incumbent upon it. Article 8 of the Regulation indicates that this concept includes the collection of information, data, and documents necessary to meet the requirements set out in the Regulation, risk assessment measures, and risk mitigation measures. Conducting a due diligence audit is an essential obligation for specific actors involved in the supply chain of EUDR-covered goods [27]. The Regulation also specifies information and documentation requirements to be appropriately addressed and verifiable, inter alia, to demonstrate that the products concerned do not cause deforestation and that the relevant commodities have been produced in accordance with the relevant legislation of the country of production, including any arrangements granting the right to use the area for the production of the commodity concerned. It is therefore important to distinguish between the legal standard of conduct imposed by the EUDR—due diligence as the obligation to collect information, assess risk, and adopt mitigation measures—and the factual basis on which that diligence relies, namely geolocation data and deforestation layers generated by systems such as PRODES or GFW. Indicator divergence primarily affects this factual layer and may therefore undermine the credibility of due diligence assessments.

Another mechanism included in the EU–Mercosur Partnership Agreement [22] is the indication in Article 18.8.2(b) of the parties' commitment to promote sustainable supply chains of timber and non-timber forest products, which are intended to be a means of improving the living conditions of forest-related local communities and indigenous peoples and promoting the conservation and sustainable use of forests. This means creating a platform for cooperation on sustainable supply chains for timber as well as other raw materials.

3. Problem with the Enforcement of Environmental Safeguards on Deforestation in the EU–Mercosur Partnership Agreement

Despite the introduction of environmental protections into the agreement, including protection against deforestation, there are numerous doubts about their enforcement [26]. The liberalization of access to the EU market for Mercosur products raises concerns that agricultural intensification may lead to increased deforestation of the Amazon.

As mentioned earlier, the Paris Agreement is a fundamental element of the EU–Mercosur Partnership Agreement [22]. In addition, in the field of environmental protection, an annex concerning Chapter 18 of the Agreement was also attached to the agreement. Part A.2 of the Act sets out specific provisions on compliance with multilateral regimes on sustainable development principles. In addition, in paragraph 15, each party committed to comply with international environmental provisions and to implement appropriate measures, in accordance with national law, to prevent further deforestation and to increase efforts to stabilise or increase forest cover from 2030, including the Paris Agreement. Another safety buffer would be a commitment not to lower the environmental protection standards provided by the applicable national regulations. This provision seems to be a legally binding obligation in the system of international law, and the possibility of suspending the agreement in whole or in part in the event of non-compliance with the provisions of the agreement allows for effective enforcement of the Parties' obligations.

In November 2024, the European Economic and Social Committee issued an opinion on deforestation in the Amazon rainforest, which was part of the impact analysis of the EU–Mercosur Partnership Agreement. It indicated that satellite images clearly indicated that forests were replaced by forest plantations, agriculture, and animal husbandry between 1988 and 2020 [27,28]. Progressive deforestation of forests means that if the necessary measures are not taken to reduce it, the forest will not be able to maintain ecological balance

without human support. In August 2025, the MapBiomass monitoring platform indicated that the largest number (74.4%) of conversions to agricultural land were made for soybean cultivation. Brazilian President Luiz Inácio Lula da Silva, on the surface of which the greatest deforestation has occurred, is striving to introduce a policy of "zero deforestation", which Brazil is to achieve by 2030 [29]. However, it is difficult to indicate whether this policy will ultimately be implemented, considering the term of office and its end in 2027, i.e., 3 years before the postulated goal. The other Mercosur countries will also be forced to eliminate deforestation in their territories.

A problem in the enforcement of environmental safeguards on deforestation in the EU–Mercosur Partnership Agreement is the difficulty in monitoring and reporting deforestation data, as well as the limited traceability of raw materials, especially as they go through a complex supply chain of agricultural and timber products. Another problem is the high risk of circumvention of regulations by using intermediaries, including those with certificates. Mercosur countries, including Brazil, are developing countries. Although Brazil has had an anti-corruption law in force since 2013, in 2023, Transparency International Brazil indicated that the anti-corruption and compliance management systems used in private companies are generally not yet fully developed and therefore need further improvement.

However, the biggest challenge may be the possibility of suspending the agreement in whole or in part in the event of non-compliance with the provisions of the agreement by one of the parties. While this mechanism is one of the most important instruments for the enforcement of obligations, in practice, its application may encounter political and economic difficulties, as it is a mechanism provided for in the event of a serious breach. On the one hand, this guarantees the stability of trade relations between the European Union and Mercosur countries, but on the other hand, it limits flexibility in responding to environmental violations, as the very concept of a 'serious violation', which is taken from Article 60 of the 1969 Vienna Convention on the Law of Treaties [30], is vague and, in practice, is relatively rarely used to justify the suspension of a treaty, which leaves considerable room for divergent interpretations. A serious breach is an exception to *pacta sunt servanda*. Importantly, not every breach is 'serious', which means that it must concern an 'essential provision' of the agreement. In protective treaties (e.g., human rights), the application of Article 60 is inherently limited, but in economic/trade agreements, it is, in principle, permissible. The EU–Mercosur agreement, which is essentially economic in nature and contains an environmental component, falls within the 'normal' scope of Article 60, and therefore a serious breach of environmental obligations may be grounds for suspending the trade benefits provided for therein [31]. However, there is a risk that this clause will be used only in a discretionary manner, depending on current political and commercial conditions, rather than on an objective assessment of the degree of breach of the environmental provisions of the agreement. The suspension of the contract itself, although it was included in its provisions, may lead to tensions in commercial relations. Undoubtedly, fears of an economic reaction may undermine the preventive effectiveness of this measure, limiting the real impact on compliance with the environmental rules contained in the agreement. Practice shows that even in the face of serious treaty violations, states do not always decide to exercise their right to terminate or suspend it. A good example of this is the bilateral disarmament treaties between the United States and Russia, in particular the New START treaty. Despite repeated allegations of a 'material breach' on the part of Russia, it remained in force for a long time because, from a political and strategic point of view, it was considered that even a flawed treaty regime provided greater predictability than a complete absence of restrictions. A similar mechanism may occur in the case of economic and environmental agreements: the fact that there are formal grounds for invoking a 'material breach' does not necessarily mean that a party will decide to

suspend or terminate the agreement if the political and economic cost of such a step would be excessive [32].

An additional problem may also be a situation in which one of the parties accuses the other of failing to comply with the provisions of the agreement, while the other party does not share this assessment, which not only weakens mutual trust but also the effectiveness of the control mechanisms provided in the agreement. Reliable and transparent systems for reporting emissions, changes in land use, and the state of forest cover will undoubtedly be the basis for assessing whether the parties are actually fulfilling their obligations under the agreement, although there are already several reporting methods. Although Article 18.10 of the Agreement indicates that scientific and technical evidence for environmental protection measures that may affect trade or investment will be based on objective, relevant international standards, guidelines, or recommendations, if any, in practice, the implementation of this assumption may be difficult. The lack of precise mechanisms for verifying evidence sources, as well as different approaches to environmental risk assessment, can lead to divergences in the application of these rules and thus undermine their protective function. The following paragraph indicates that in cases where scientific evidence or information is insufficient or inconclusive, and there is a risk of serious deterioration of the environment or a risk to occupational health and safety in its territory, the party may adopt measures based on precautionary principles. In addition, a party adopting measures based on the precautionary principle should take steps to obtain new or additional scientific information necessary for a more unambiguous assessment and review such measures accordingly, which may raise major concerns about the desire of either party to avoid taking the initiative to update or implement the measures, thereby delaying their application and limiting the effectiveness of prudential mechanisms. Therefore, effective monitoring of climate change and deforestation should be one of the key aspects of the Agreement, although in practice it may turn out to be a demanding and difficult task.

Although political and economic considerations may discourage the European Union from actually activating the mechanism for suspending the agreement with Mercosur countries, in the event of a serious breach of environmental commitments, the very existence of a credible mechanism exerts preventive pressure. The threat of suspension may act as a deterrent *ex ante*, as Mercosur countries will have an incentive to comply with agreed standards and avoid the risk of losing trade benefits [33]. However, when deforestation indicators diverge structurally, and parties can plausibly contest the underlying data, the credibility of this threat is weakened, because potential violators may challenge whether the conditions for a "serious breach" are in fact met.

The economic pressure to increase agricultural production and exports at the expense of forests, which may intensify after the signing of the agreement, poses a risk of intensification of deforestation in the very short term [34]. There is a fear that producers, in order to maximize profits before full environmental restrictions come into force, will be willing to accelerate the removal of forest cover by 2030 to acquire as much forest as possible for their crops. This development is confirmed by the significant deforestation in the last month of the previous president's office, Jair Bolsonaro, who allowed the deforestation of the Amazon [35].

4. Methodology and Findings

For the purposes of this article, two indicators measuring the scale of deforestation were compared to examine potential problems with deforestation evaluation: the PRODES indicator and the Global Forest Watch indicator. During the preparation of this manuscript, the authors used GenAI for the purposes verify the accuracy of the data.

There are several indicators used to determine the scale of deforestation in the Amazon. These include PRODES (Projeto de Monitoramento do Desmatamento na Amazônia Legal) [36], by Terra Brasilis and Brazil's National Institute for Space Research (INPE). This indicator is recognized as an official standard, used by Brazilian state institutions such as IBAMA or MMA, and other research institutions. It focuses mainly on deforestation on an industrial scale, recording areas of at least 6 hectares and over. Research conducted by INPE is also the basis for such indicators as DETER, MapBiomass, or RAISG.

Another independent, albeit also financed from the budgets of various governments, indicator, the Global Forest Watch [37], records much smaller areas (as much as 0.09 ha) in which even natural tree stand die-offs are recorded, which are not significant from the perspective of industrial logging. Importantly, PRODES analyses are validated by analysts to interpret the origins of deforestation (anthropogenic or non-anthropogenic) and also focus on primary forests such as the Amazon. Thus, it is a more appropriate indicator to determine the impact of product exports on deforestation. However, to consistently examine the measurement methods and to deepen the conclusions as much as possible, the relationships between these indicators were analyzed. First, the data were normalized to hectares and presented in the graphic below (PRODES presents data in km^2, while GFW measures data in Mha). To maintain data consistency, the survey was conducted between 2002 and 2024 (GFW data are available from 2002). Given the limited sample size reduces the analytical robustness, the regression results should be viewed as suggestive rather than conclusive. However, in light of the urgency of the matter, we consider it important to present these preliminary findings. Moreover, these models are based on annual observations; thus, they may exhibit serial correlation and other time-series properties. Because the regressions were not explicitly adjusted for these, the reported standard errors and *p*-values should be interpreted with some caution. Comparison of PRODES and GFW scores ($km^2 \times 100$) shows Figure 1.

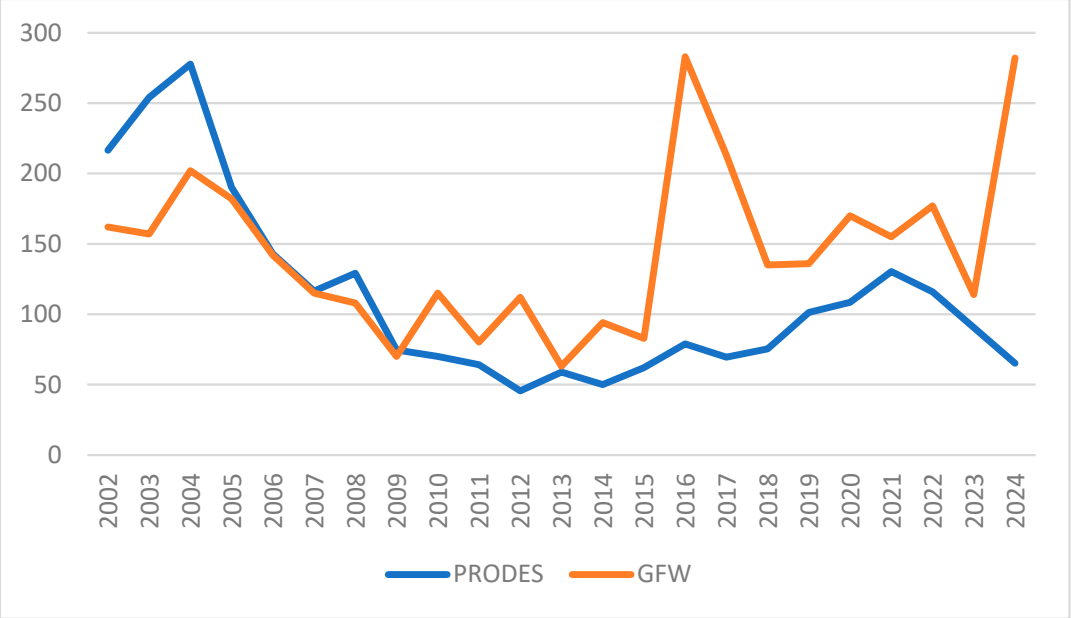


Figure 1. Comparison of PRODES and GFW scores ($km^2 \times 100$). Source: data from the PRODES [36] and GFW [37] websites.

The following are the results of the full scale of the PRODES study, which is much longer than the GFW study (shown in the Figure 2).

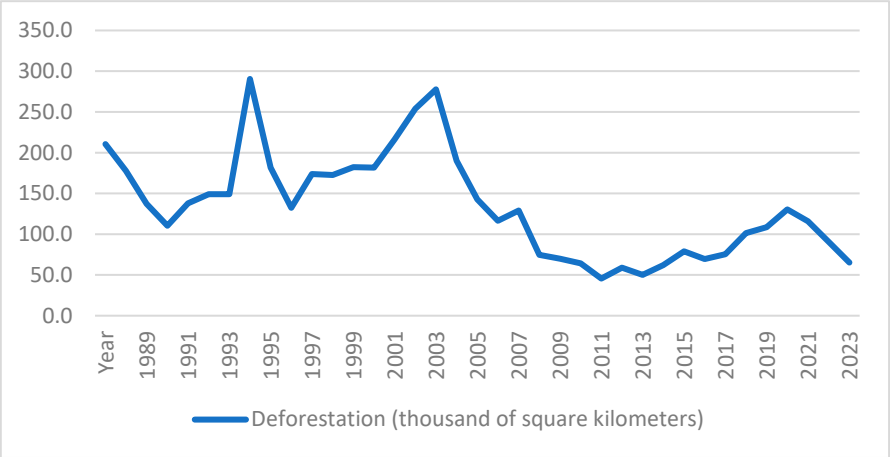


Figure 2. Deforestation in PRODES data (1988–2024) (km^2 × 100). Source: data from the PRODES [36] website.

The visual analysis reveals that although the PRODES results were higher in the beginning, already in the years 2004–2006, these data indicated very similar values, while since 2009, the GFW results have been significantly higher than the PRODES results. Initially, the higher results may have been due to the less precise operation of the GFW sensors, as well as mixed vegetation that the automatic sensors were unable to detect, or definitional differences (although the GFW indicates that a significant definition change occurred in 2015). Data from 2008 indicate very similar results of PRODES and GFW, and since 2009, the GFW index has already presented a higher deforestation rate. In the following years, GFW registered several significant peaks that deviated significantly from the results of PRODES: in 2016 and 2024. In 2015–2017 and 2023–2024, Brazil was hit by droughts and fires. This kind of damage is not recorded by PRODES. However, it is worth noting a very important difference between the results of PRODES and GFW in 2024—while the results of PRODES are decreasing, the results of GFW are increasing. This may indicate small-scale logging that PRODES is unable to record (e.g., fragmented deforestation, stealth clearing, deforestation under the radar), carried out quickly due to the anticipated implementation of the agreement with the EU and the EUDR Regulation, avoiding the consequences of the implementation of traceability standards that could trigger the effects of the agreement. Although the credibility of such moves may be limited due to the difficulties in coordinating such actions and their inefficiency, this does not mean that smaller entrepreneurs could not try to evade the EUDR regulation in these ways. Such felling would also not be intended for industrial purposes. It is possible to notice it using complementary PRODES methods, such as DETER-B, DEGRAD, or others. Some studies indicate that in the post-2010 regions of Pará and Rondônia, small-scale deforestation may indeed take place, especially among smallholder farmers, in areas with unclear ownership structures [38–40]. However, it is possible that larger producers may pay small farmers as "frontier contractors" for this purpose. Such smaller fragments may be consolidated and accumulated in the future after the legalization process, although these do not necessarily have to be strategic actions. Faced with increasing traceability pressures under the EU–Mercosur Agreement and the EUDR, smuggling operators may prefer small, dispersed acreage to reduce visibility or delay detection until export audits have adapted. The PRODES indicator may underestimate the total number of dispersed, small slices, but it still accurately reflects the conversion to industrial scale, which is the main goal. Nevertheless, the potential existence of such a problem may indicate a significant governance problem. At a time when deforestation control is more rigorous, this problem may be more common among smaller, dispersed actors whose performance may go beyond

PRODES analysis. This should be understood as a tentative hypothesis about possible strategic behavior rather than a demonstrated causal explanation; alternative drivers such as climatic shocks and domestic policy dynamics may also play an important role.

First, descriptive statistics were analyzed between two indicators, which show that GFW reports on average about 30% higher losses than PRODES, indicating a broader definition of GFW and PRODES' focus on industrial deforestation. PRODES captured the industrial boom of 2002–2004 more strongly, while GFW captured the degradation and fires of 2016–2024 (Table 1).

Table 1. Descriptive statistics of deforestation in the years 2002–2024.

	PRODES	GFW
Average	1.13 million ha	1.46 million ha
Median	0.91 million ha	1.36 million ha
Standard deviation	647 thousand hectares	594 thousand hectares
Minimum	457 thousand hectares (2012)	632 thousand hectares (2012)
Maximum	2.78 million hectares (2004)	2.83 million hectares (2016 and 2024)
Shapiro–Wilk	$p < 0.05$	$p = 0.09$

Source: own study.

Then, between the PRODES and GFW indicators, Pearson, Spearman, and Kendall correlation analyses for the years 2002–2024 were also carried out. The results of the Shapiro–Wilk test indicate that the data are not parametric, so the results of the Spearman test are more suitable for these kinds of data. The results are shown in Table 2.

Table 2. Correlation matrix test results for PRODES and GFW indicators.

Indicator	Value	Significance (p)	Interpretation
R Pearson	0.264	0.223	Weak, insignificant statistical correlation
Spearman's	0.488	0.018	Moderate, significant rank correlation. Similar directions of change
τ-b Kendall	0.349	0.020	Low-moderate, significant correlation. Directional convergence occurs

Source: own study.

Given that the data are nonparametric, Spearman and Kendall coefficients provide the more appropriate measures of association. The Pearson correlation is reported solely for completeness and should not inform substantive interpretation; as expected, it shows only a weak positive association and is not statistically significant. On the other hand, Spearman's correlation, which is more valid for these types of data, indicates a moderate and statistically significant rank correlation, which means that the correlation between these indicators is characterized by a nonlinear or monotonic, but not completely linear correspondence, i.e., they have a similar but not proportional direction. This means that there is a moderate trend towards deforestation in the Amazon in general, as the regressions show.

However, it is hard not to notice that there are significant divergences between these indicators, which have been tested using linear regressions that examine the divergence trend. To do this, two differences between the PRODES and GFW indicators were first calculated: the raw difference (i.e., preserving the negative numbers, which occur especially after subtracting the GFW value from the PRODES value) and the absolute difference (i.e.,

using absolute values). This is illustrated in Figures 3 and 4. The patterns and visual representation of these differences are presented below:

$$\text{Raw Divergence: } D_{raw,t} = \text{PRODES}_t - \text{GFW}_t \quad (1)$$

$$\text{Absolute Divergence: } D_{abs,t} = |\,\text{PRODES}_t - \text{GFW}_t\,| \quad (2)$$

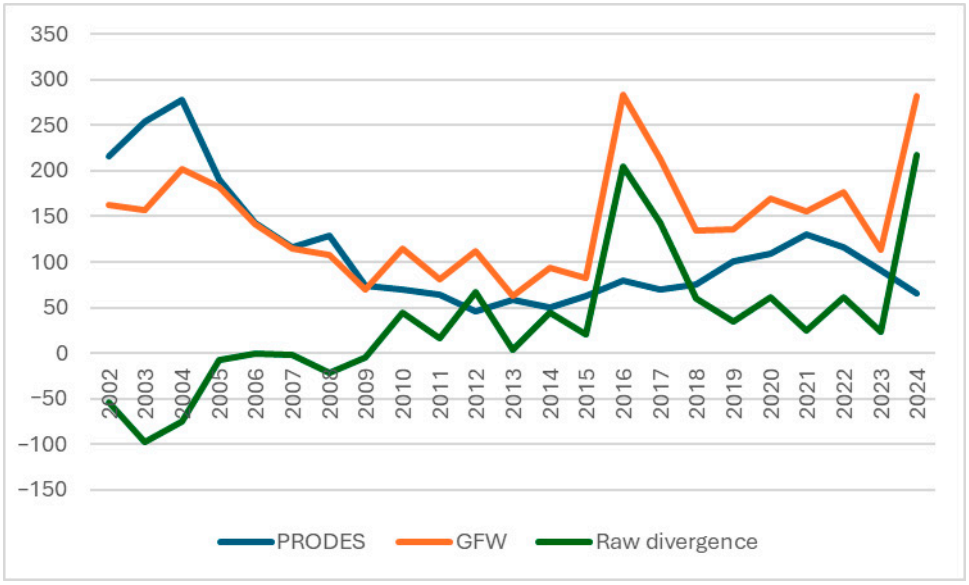


Figure 3. Raw divergence between PRODES and GFW (km^2 × 100). Source: own study, based on PRODES [36] and GFW [37] data.

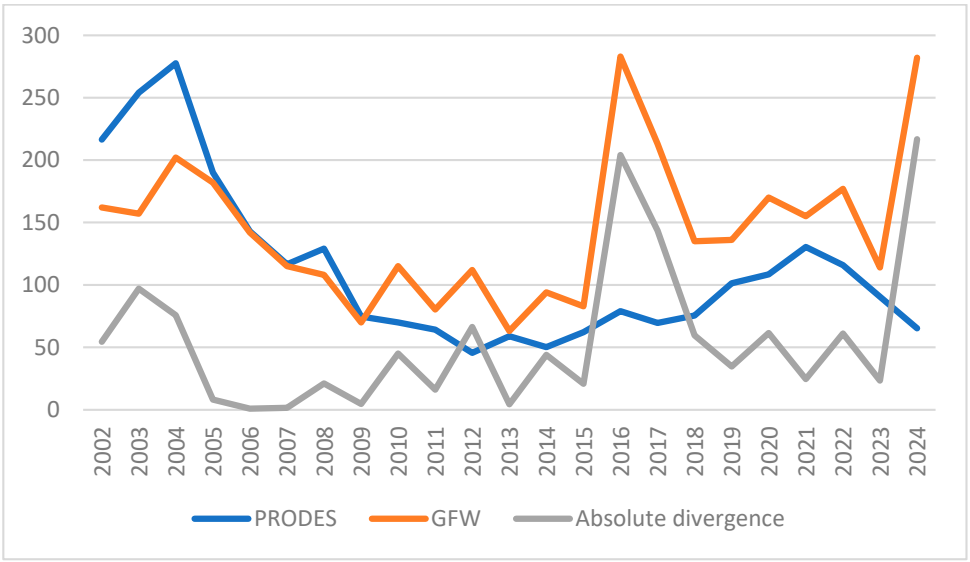


Figure 4. Absolute divergence between PRODES and GFW (km^2 × 100). Source: own study, based on PRODES [36] and GFW [37] data.

A preliminary visual analysis of the absolute divergence indicates a significant "gravity" of the difference towards higher values of the GFW ratio, especially in moments of intensifying differences between the two indicators. To statistically verify this phenomenon, a *t*-test for dependent samples was used to assess the mean differences between two variables. The hypotheses put forward for the purpose of investigation are as follows:

$$H0: \mu_{GFW} = \mu_{PRODES} \quad (3)$$

$$H1: \mu_{GFW} > \mu_{PRODES}$$

The test results are shown in Table 3.

Table 3. The *t*-test results for dependent samples between PRODES and GFW.

Statistics	PRODES	GFW	Difference	*T*-Test	Wilcoxon's Test
Average	113	146	−33.1	t (22) = −2.11	w = 73
Median	90.6	136	−26.6		
SD	64.8	59.4			
95% CI for difference			[−65.8, −0.54]		[−55.1, −1.15]
p-value				0.047	0.048
Effect size				d = 0.44	r = 0.47

Source: own study, based on PRODES [36] and GFW [37] data.

The *t*-test results indicate an average higher GFW score than the GFW index by 3300 km^2, confirmed by the Wilcoxon test for nonparametric data, which indicates the systematic, non-random nature of the divergence and numerically confirms the visually identified "gravity". This average divergence of 3300 km^2 per year corresponds to an area slightly larger than Rhode Island (USA), about 1.3 times the size of Luxembourg, and roughly twice the area of the city of São Paulo.

Next, linear regression was used (using the raw difference shown earlier in the graph) to examine the divergence trend with the following formula:

$$Diff_t = \alpha + \beta \cdot Year + \varepsilon_t \quad (4)$$

where

$Diff_t$—the difference between PRODES and GFW;
Year—the year in which the difference occurs.

The results of the regression are shown in Table 4.

Table 4. Linear regression results for identifying linear divergence trends.

Predictor	Coefficient	SE	t	*p*	R	R^2
Intercept (α)	−15,472.92	3522.33	−4.39	<0.001	0.693	0.48
Year (β)	7.7	1.75	4.40	<0.001		

Source: own study.

A coefficient of β, equal to 7.7, indicates that the average difference between GFW and PRODES between 2002 and 2024 is growing by 7700 km^2 per year, and this upward trend is statistically significant ($p < 0.001$). The R^2 model fit measure of 0.48 indicates that the time trend explains 0.48 variation of the difference.

Next, the nonlinearity of the trend was tested using the following model:

$$Diff_t = \alpha + \beta_1 \cdot Year + \beta_2 \cdot Year^2 + \varepsilon_t \quad (5)$$

where

$Diff_t$—the difference between PRODES and GFW;

Year—the year in which the difference occurs;
Year^2—a year squared to measure the rate at which divergence accelerates (or slows down).

The result of the model is shown in Table 5.

Table 5. Testing the nonlinearity of the divergence trend by year.

Predictor	Coefficient	SE	t	*p*	R	R^2
Intercept (α)	−76.682	31.826	−2.41	0.026	0.714	0.510
Year (β_1)	14.874	6.702	2.22	0.038		
Year^2 (β_2)	−0.326	0.294	−1.11	0.281		

Source: own study.

The β_1 coefficient is almost 14,900 km^2 per year, and is statistically significant (p = 0.038), which confirms the overall trend of divergence. On the other hand, the non-linear component β_2 is −0.326, which could suggest a slight slowdown in the divergence in the trend (despite a significant increase in divergence in 2024), but it is not statistically significant (p = 0.281), which indicates that changes in the rate of divergence cannot be confirmed (there are no statistically significant slowdowns or accelerations in the trend), and thus the linear trend may better explain the changes occurring between these indicators. Although this model explains 51% of the variation in difference, which is 3 percentage points more than the linear model, the small sample of N = 23 (2002–2024) makes it difficult to identify significant curvatures from randomness.

A proportional cleavage analysis was then performed. It is a regression in which the dependent variable is the PRODES indicator, and the covariates are GFW and the quadratic covariate GFW:

$$PRODES_t = \beta_0 + \beta_1 \cdot GFW_t + \beta_2 \cdot GFW_t{}^2 + \varepsilon_t \quad (6)$$

This model explains the 0.381 variation of PRODES by the magnitude of the GFW index and the quadratic covariate, showing a moderate relationship (Table 6).

Table 6. Testing the nonlinearity of the divergence trend on GFW.

Predictor	β (Estimate)	SE	t (df = 20)	*p*	R	R^2
Intercept	−140.46	70.53	−1.99	0.069	0.617	0.381
GFW	3.1556	0.921	3.43	0.003		
GFW^2	−0.00840	0.00264	−3.18	0.005		

Source: own study.

Both GFW and GFW^2 show high statistical significance (p = 0.003 and p = 0.005, respectively). However, both terms are characterised by opposite signs: as GFW increases, the linear term pushes PRODES upwards, while the quadratic term pulls it downwards. This indicates that PRODES and GFW move broadly together when changes in deforestation are small, but that PRODES increases less than proportionally when GFW reports very high tree-cover loss. In other words, the two indicators are most closely aligned in "normal" years and diverge most strongly in years of extreme forest loss, when PRODES does not increase at the same rate as GFW, and the proportions between the indicators are most distorted.

Finally, two sub-periods (2002–2014 and 2015–2024) were tested, which is substantively justified due to the change in the methodology of data collection in the GFW indicator. To interpret the differences, a *t*-test and a linear regression (Table 7) were performed for both sub-periods.

Table 7. Statistical results of the sub-period study.

Period	Average	SD	t (df)	*p*	95% CI Difference	D Cohen
2002–2014 (N = 13)	33.8	31.3				
2015–2024 (N = 10)	85.0	66.8	t (21) = −2.22	0.038	[−98.7, −3.8]	0.93
Welch's correction			t (14.5) = −2.02	0.067	[−107.8, 3.2]	
Mann–Whitney's test			U = 34.0	0.057		

Source: own study.

The results show a statistically significant difference in the level of absolute divergence between the two indicators was on average more than twice as high (from an average of 33.8 to 85 units, thus almost tripling) in 2015–2024 compared to the earlier period of 2002–2014. In addition, the Welch correction indicates a much greater volatility in the later sub-period; the pattern in the second sub-period appears more irregular, with pronounced peaks in 2016 and 2024. A linear regression was then created for both sub-periods.

The results presented in Table 8 indicate that while the period 2002–2014 indicated a moderate but stable increase in the divergence between PRODES and GFW, the 2015–2024 sub-period was characterized by a lack of trend and irregularity. This indicates that the GFW reacts to short-term changes in the second sub-period rather than to long-term increases in the differences with respect to the PRODES.

Table 8. Linear regression results for the 2002–2014 and 2015–2024 sub-periods.

Period	Regression Model	β (Slope)	SE	t (df)	*p*	R^2
2002–2014	AbsDiv = α + β · Year	+1.57	0.66	2.38	0.035	0.31
2015–2024	AbsDiv = α + β · Year	+0.05	8.78	0.01	0.995	~0.00

Source: own study.

5. Discussion

The results of the empirical analysis showed a systematic, statistically significant divergence between the two main indicators of deforestation—the Brazilian PRODES and the Global Forest Watch, a global indicator recognized as independent. This difference, which has persisted and increased since 2015, is not merely the result of random factors. In practice, measurement discrepancies translate directly into the possibility of demonstrating whether and to what extent there has been a breach of environmental obligations enshrined in the EMPA. The discussion that follows is based on a combination of three analytical layers, which we consider essential for linking the empirical results to their legal and behavioral implications. First, the time-series data show what happens at the level of reported deforestation (trends, divergence, and outliers in PRODES and GFW). Second, on that basis, we can highlight key differences in the measurement properties and methodological design of the indicators, including their different detection thresholds and definitional choices. Third, we consider how governments, producers, or intermediaries may react to these legal and empirical settings.

The fundamental problem is that the effectiveness of environmental clauses in a contract depends on the empirical possibility of confirming the fact of deforestation using the appropriate metrics. The use of different measurement methods by the parties results in the fact that the identical state of the environment may be assessed differently depending on the reference system adopted. PRODES, which is a Brazilian indicator, focuses on industrial deforestation and does not record fragmented deforestation or stealth clearing. Meanwhile, the GFW, which relies on more sensitive sensing and a broader definition of

tree cover loss, also includes changes that are not included in the national data. Thus, it can generate data with greater transparency, which would be less susceptible to corruption. A significant discrepancy between these indicators is illustrated by data from 2015–2024, where the difference between their results in this period was more than twice as large as in previous years.

Such a discrepancy has fundamental consequences for the enforceability of environmental clauses. Article 18.13 of the EU–Mercosur Partnership Agreement provides for the possibility of suspending its implementation in the event of a "serious breach" of environmental provisions. However, the concept of "serious breach" itself is not precisely defined in the contract, which makes it an evaluative concept and open to political, and thus also legal, interpretation. In this context, divergent PRODES and GFW figures—and, by extension, other indicators—may lead to disputes over whether the evidentiary record is sufficient to trigger this clause. Brazil, relying on the national indicator, could argue that there has been no violation, while the EU—citing the GFW—could claim otherwise. For instance, if over several years PRODES reported an average annual deforestation of around 1.1 million hectares while GFW reported about 1.5 million hectares for the same period, Brazil could rely on the lower figure to deny any "serious breach", whereas the EU could invoke the higher one to claim that the environmental provisions had been violated. Whether such a situation meets the threshold of a "serious breach" would then depend both on how the environmental provisions of EMPA are interpreted in light of Article 60 of the Vienna Convention (in particular, whether they are treated as "essential provisions") and which indicators—or basket of indicators—are recognised as authoritative evidence. In such circumstances, an "enforcement gap" emerges: obligations formally exist, but their application becomes practically impossible in the absence of a shared evidentiary basis [41].

The divergence of indicators thus reveals a deeper structural problem: the dependence of the effectiveness of the provisions of the contract on the quality and consistency of the data on which they are based. In this case, it is not the content of the contract itself, but its empirical background—monitoring and reporting systems—that determines whether environmental clauses will work in practice [42]. The statistical data, which in the study showed a systematic increase in the differences by about 7700 km^2 per year, show that the difference between the official Brazilian monitoring and the global data is permanent and structural. In the long term, this may lead to an information asymmetry between the parties to the agreement: the EU will be willing to interpret the data in a strict way, in line with the logic of the EUDR, while Mercosur may challenge these conclusions by relying on its own sources and definitions.

In the practice of enforcing EU law, such asymmetry weakens the preventive function of clauses. Since the reliability of the data itself can be undermined, sanction mechanisms become a negotiating instrument rather than a tool for environmental protection. As a result, even serious violations, such as a sharp increase in deforestation in a particular region, may not lead to the suspension of the agreement, as the agreement lacks a common methodology to confirm the scale of the phenomenon.

This phenomenon also has wider implications for the EUDR, which imposes due diligence on importers regarding the origin of commodities associated with the risk of deforestation. The effectiveness of this legal regime depends on the reliability of data on the origin of raw materials, which are supposed to confirm that the product does not come from deforested areas. However, if the PRODES data do not capture small-scale changes in forest cover, it is possible for commodities to meet the formal EUDR requirements even though they actually contribute to environmental degradation. In this way, the imperfection of the indicator becomes a legal gap, allowing the purpose of regulation to be circumvented [43].

It is worth pointing out that the measurement differences, which are revealed in the data, especially after 2015, can be interpreted as a symptom of limited institutional supervision and fragmentation of the environmental data management system. In the context of the EU–Mercosur agreement, this means that the lack of harmonised reporting standards can become a tool of strategic evasion—parties can selectively rely on data that are more politically or economically advantageous to them. Thus, divergence not only hinders the assessment of compliance with the agreement but also undermines institutional trust between the parties, which is a prerequisite for the effective implementation of sustainable development mechanisms [42].

The analysis suggests the need for new solutions that could reduce the risk of data instrumentalization. Among these, consideration should be given to the creation of a joint platform for the verification of deforestation indicators, coordinated by EU and Mercosur research institutions or independent organisations, as well as a mechanism that would allow independent experts to settle disputes over the measurement methodology. To give such a platform an institutional anchor within EMPA, we suggest establishing a standing joint technical body under the agreement's Trade and Sustainable Development framework, mandated to review methodological changes and validate deforestation data on a regular basis. Instead of relying on a single national metric (which creates a risk of conflict of interest) or a single external one (which may lack local context), the dispute-settlement mechanism should rely on a "basket of indicators" combining national monitoring systems such as PRODES with independent global products such as GFW, complemented where appropriate by ground-based checks and disclosure requirements. In parallel, it would be important to clarify more precisely what constitutes a "serious breach" in the environmental context and to link this concept explicitly to the agreed evidentiary framework. In other words, the EMPA and similar agreements need not only institutional mechanisms, but also a clearly specified set of metrics and data sources that parties accept as the primary basis for determining whether environmental obligations have been breached. Furthermore, our analysis suggests that the divergence between indicators is structural rather than temporary, stemming from inherent differences in definitions, sensor sensitivities, and institutional mandates. Consequently, the legal design of future agreements must move away from enforcement models that implicitly privilege a single indicator or cut-off date towards a robust, multi-source evidentiary framework, in which enforcement is based on the convergence of multiple evidence streams rather than a single contested statistic.

Absent such reforms, the divergence between PRODES and GFW is not a purely methodological problem but reveals a fundamental limitation of the effectiveness of the suspension of the application of contractual provisions. The lack of consistent, mutually recognized measurement standards means that environmental clauses, even if formally binding, can remain practically unverifiable. As a consequence, the growing ambiguity of empirical data not only complicates the assessment of the state of the Amazon forests but also undermines the credibility of the entire EU–Mercosur enforcement system, which is based on the assumption of an objective and shared understanding of environmental facts [42,44].

6. Conclusions

Deforestation is one of the most serious challenges to the effective implementation of the partnership agreement between the EU and Mercosur. Although parties declared commitment to sustainable development and the inclusion of provisions relating to environmental protection in the content of the agreement, enforcement mechanisms remain limited, inter alia, by the imprecise indication of deforestation control systems in Mercosur member states. Analysis of the content of the agreement, as well as the data of PRODES

and GFW, shows the possibility of a short-term increase in pressure on South American forest resources. Therefore, the lack of effective instruments for verifying the origin of raw materials and transparent systems for monitoring supply chains may exacerbate the risk that the conclusion of the EU–Mercosur Partnership Agreement will, in practice, promote rather than reduce deforestation processes. By combining legal–institutional analysis with a time-series comparison of PRODES and Global Forest Watch data for 2002–2024, this article shows that the design of environmental clauses and their empirical underpinnings must be considered together if the agreement is to deliver on its sustainability ambitions.

Our empirical results document a systematic and statistically significant divergence between PRODES and GFW, which has widened structurally since 2015. On average, GFW reports around 30% higher annual forest loss than PRODES, corresponding to about 3300 km^2 per year—an area comparable to a small European region. These patterns are consistent with the different detection thresholds and definitional choices of the two indicators: PRODES focuses on large-scale, clear-cut deforestation, whereas GFW also captures more fragmented loss and fire-related degradation. As a result, the same dynamics of forest change can be presented very differently, depending on which indicator is used. Beyond the legal questions addressed in this article, these results also provide a useful heuristic benchmark for comparing the reported scale of deforestation in the Brazilian Amazon across different datasets.

Legally, this structural indicator divergence creates an enforcement gap. Environmental obligations in the EMPA, and the possibility of suspending trade preferences in case of a "serious breach", depend on empirical evidence whose magnitude and even direction can be contested. Similar tensions arise for due diligence assessments under the EUDR, where commodity flows may satisfy formal requirements while still contributing to unrecorded forest loss. To narrow this gap, we suggest institutional and evidentiary reforms: a joint EU–Mercosur platform and a standing technical body for validating deforestation data, the use of a basket of indicators rather than a single metric, and a clearer link between the notion of "serious breach" and an agreed evidentiary framework. Research communities working on forestry, remote sensing, and environmental governance can help develop, test, and harmonize such indicators, thereby anchoring future trade and forest-governance regimes in more robust, multi-source evidence.

Author Contributions: Conceptualization, I.O., K.K. (Katarzyna Krupska) and K.K. (Katarzyna Kosior); methodology, I.O. and K.K. (Katarzyna Krupska); software, I.O.; formal analysis, K.K. (Katarzyna Krupska).; investigation, I.O. and K.K. (Katarzyna Krupska); data curation, I.O.; writing—original draft preparation, I.O., K.K. (Katarzyna Krupska) and K.K. (Katarzyna Kosior); writing—review and editing, I.O., K.K. (Katarzyna Krupska) and K.K. (Katarzyna Kosior); visualization, I.O.; supervision, K.K. (Katarzyna Kosior). All authors have read and agreed to the published version of the manuscript.

Funding: The article processing charge (APC) was funded by the National Support Centre for Agriculture (KOWR) under contract No. CEN.BDG.WP.6515.2.2025.EJ.57.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Acknowledgments: The study is the result of cooperation between researchers from the Institute of Agricultural and Food Economics—National Research Institute, Warsaw, Poland. While preparing this manuscript, the authors used GenAI to verify the accuracy of the data. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

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