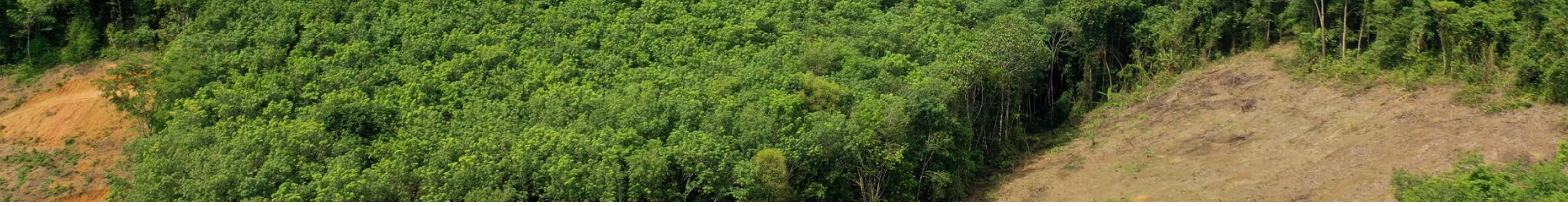

Carbon Credits in the Amazon
New Methodology for Assessing Project Additionality

CLIMATE POLICY INITIATIVE

PUC RIO

INSIGHT
SEPTEMBER 2025

Introduction

As the climate crisis intensifies, so does the demand for effective mechanisms to mitigate greenhouse gas (GHG) emissions. Carbon markets have emerged as a promising solution, enabling companies and countries to finance emission reduction and removal actions, often in territories far from where their emissions have occurred. In the voluntary market—where companies and organizations purchase credits in response to climate commitments, rather than due to legal requirements—significant shares of traded credits originate from Nature-Based Solutions (NbS), with a particular emphasis on forest conservation.

Brazil holds a prominent position in this context, with vast potential for generating carbon credits through the preservation of tropical forests. Most of the existing projects in the country employ the mechanism known as **REDD** (Reducing Emissions from Deforestation and Forest Degradation), which aims to incentivize the reduction of GHG emissions resulting from deforestation and forest degradation.[1]

The environmental integrity of these credits depends on a key criterion: **additionality**. For a carbon credit to be valid, it is necessary to demonstrate that the emission reduction occurred solely because of the projection, in other words, that the forest would have been cleared in the absence of that conservation initiative. Assessing this additionality requires the definition of a **counterfactual scenario**, known as the **baseline**, which represents what would have happened to that area had the project not existed.

Traditionally, the methodologies used to estimate the baseline rely on statistical and spatial analyses, such as the extrapolation of historical deforestation trends. However, recent studies have highlighted significant flaws in this approach. Critics argue that these methodologies allow a certain degree of manipulation to maximize the number of credits generated. This undermines the credibility of the projects and, consequently, of the market.

In this study, researchers from Climate Policy Initiative/Pontifical Catholic University of Rio de Janeiro (CPI/PUC-RIO) propose a new methodology for defining the baseline and projecting deforestation on private properties in the Amazon, enabling the construction of scenarios for assessing additionality in REDD projects in Brazil.[2] This methodology is based on recent literature that investigates land use dynamics from the perspective of producers regarding the most profitable use of land, with consideration for economic conditions and the characteristics of their properties.

1 In this publication, the definition of REDD is restricted to activities related to the generation of carbon credits in the voluntary carbon market from forest conservation. Within the context of the international regime, the concept of REDD is broader, focused on avoided deforestation. For more information: UNFCCC. *What is REDD+?* nd. bit.ly/44KYUyL.

2 This publication is based on the author's master's thesis. Learn more at: Arbache, João P. F. "Additionality in Carbon Projects: Evidence from the Brazilian Amazon". Master's thesis, PUC-RIO, 2024. bit.ly/4noiclH.

The results indicate that 77% of the carbon traded for REDD projects in the Brazilian Amazon is additional, with significant variations across different regions of the biome. This analysis adopts the concept of the "five Amazons" and finds high rates of additionality for *non-forest, under pressure*, and *deforested* regions, while the *forested* regions show significantly lower rates.[3,4]

These results reinforce that additionality is necessary: 23% of the forest areas that received resources from REDD projects would have remained protected even without the projects' incentives. Also, the fact that around 77% of the supported areas were conserved due to project interventions suggests that, overall, the mechanism has worked relatively well as a conservation tool. Furthermore, since REDD credit prices are relatively low compared to other carbon pricing mechanisms, the financial impact of potentially non-additional credits is limited. Concerns about additionality, however, should guide continuous project improvement, enabling carbon markets to consolidate and expand their contribution to climate change mitigation.

Carbon Markets

Carbon markets have grown in recent years, emerging as a potential solution to mitigate climate change. These markets price GHG emissions, facilitating emissions reductions through market mechanisms. There are two main types of carbon markets: regulated and voluntary.

In regulated markets, companies use credits to comply with current legislation, operating through carbon taxes or Emissions Trading Systems.[5] In voluntary markets, which are the focus of this publication, companies monitor their emissions and purchase carbon credits to offset them and achieve climate commitments without legal requirements. They calculate their GHG emissions and finance activities that reduce or remove emissions from the atmosphere, demonstrating their commitment to mitigating climate change to consumers and investors.

Voluntary carbon markets have seen annual trading exceed US$ 2 billion in recent years, highlighting their growing relevance.[6] A considerable portion of the credits produced and purchased worldwide come from NbS, such as restoration and forest conservation. Brazil stands out in the production of this type of credit, with the potential to be the largest producer of NbS credits in the world.[7]

A major concern associated with carbon credit, especially those linked to conservation activities, relates to the additionality and permanence of these activities.[8] To be additional, the credit must be associated with an area that would be deforested in the absence of the project. To be permanent, the avoided emissions must prevail in the long term, ensuring the continued conservation of the area. These conditions are crucial for projects seeking to benefit from carbon credits. However, verifying that projects are in fact following these criteria is not simple, posing a major challenge for carbon markets.

3 Veríssimo, Beto et al. *The Five Amazons: basis for the sustainable development of the Brazilian Amazon.* Amazon 2030, 2022. bit.ly/3Uh3xvC.
4 The five Amazon categories are divided into non-forest, under pressure, deforested, forested, and urban. For this analysis, we exclude the urban category, as it is not relevant to the context under consideration.
5 Learn more at: ICAP. *About Emissions Trading Systems.* nd. bit.ly/42Hhc4w.
6 EM. *2024 State of the Voluntary Carbon Market (SOVCM).* 2024. Access date: January 14, 2025. bit.ly/4fZ1Ue8.
7 McKinsey & Company. *The green hidden gem – Brazil's opportunity to become a sustainability powerhouse.* 2022. Access date: February 3, 2025. bit.ly/40Kz9MU.
8 West, Thales A. P. et al. "Action needed to make carbon offsets from forest conservation work for climate change mitigation". *Science* 381, no. 6660 (2023): 873–877. bit.ly/3WeGi6M.

These challenges are particularly complex in Brazil, where most REDD projects are based on avoided unplanned deforestation (AUD). Defining the baseline and proving additionality becomes especially difficult in these situations, as it involves estimating the risk of illegal deforestation by agents external to the property. This increases uncertainty about what would have happened in the absence of the project, making it even more essential to improve the criteria and tools for certifying additionality and permanence in carbon markets.

REDD – Methodologies and Challenges

In Brazil, several REDD projects conserve private forest areas with the goal of preventing deforestation. By receiving income from carbon credits, the preservation of these areas becomes economically viable for their landowners. In the baseline scenario, where they do not receive these revenues, their properties would be deforested—either by them or by external agents. The number of credits and revenue generated within a property are determined by the volume of carbon emissions that would have occurred in the absence of the conservation efforts implemented there.

The main methodologies used to estimate the baseline and, consequently, quantify the additionality and emissions avoided by the project are developed by Verra, the world's largest carbon credit certifier.[9] These methodologies aim to standardize the calculation of GHG emission reductions from deforestation, which can occur through both illegal activities, such as timber extraction and illegal logging, and through legal activities, such as authorized deforestation for agricultural purposes. This process involves estimating carbon stocks and deforestation rates, which is traditionally done using spatial and statistical models.

Despite the rigor required, the implementation of REDD projects remains controversial. Critics point out that the methodologies for establishing baselines can be manipulated to inflate the number of credits generated.[10] With traditional methodologies, developers have the flexibility to choose which areas and periods will serve as input for the models, which may encourage the selection of areas and periods that maximize the number of credits generated.

In response to these concerns, Verra, responsible for setting global standards for climate action and sustainable development, has updated its methodologies for REDD projects, with the goal of making them more reliable and less susceptible to manipulation.[11] Some of the key changes include the adoption of deforestation baselines calculated by Verra or by the jurisdictions where the projects are located—using official data rather than calculations by developers, who previously had the flexibility to choose models, reference regions, and time windows—and the use of remote sensing and artificial intelligence to monitor deforestation, generating more accurate data. The new baselines will follow historical averages of deforestation, making them more conservative than those using other types of modeling.[12] These changes are expected to increase confidence in the estimates and impact of REDD, boosting demand for this type of credit and, consequently, financing for these activities.

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9 EM. *2024 State of the Voluntary Carbon Market (SOVCM)*. 2024. Access date: January 14, 2025. bit.ly/4fZ1Ue8.

10 West, Thales A. P. et al. "Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon". *Proceedings of the National Academy of Sciences* 117, no. 39 (2020): 24188–24194. bit.ly/4jhFlEr.

11 Verra. *Setting the Standard: Verra's Revolutionary New REDD Methodology*. 2023. Accessed January 14, 2025. bit.ly/4fWZX1Z.

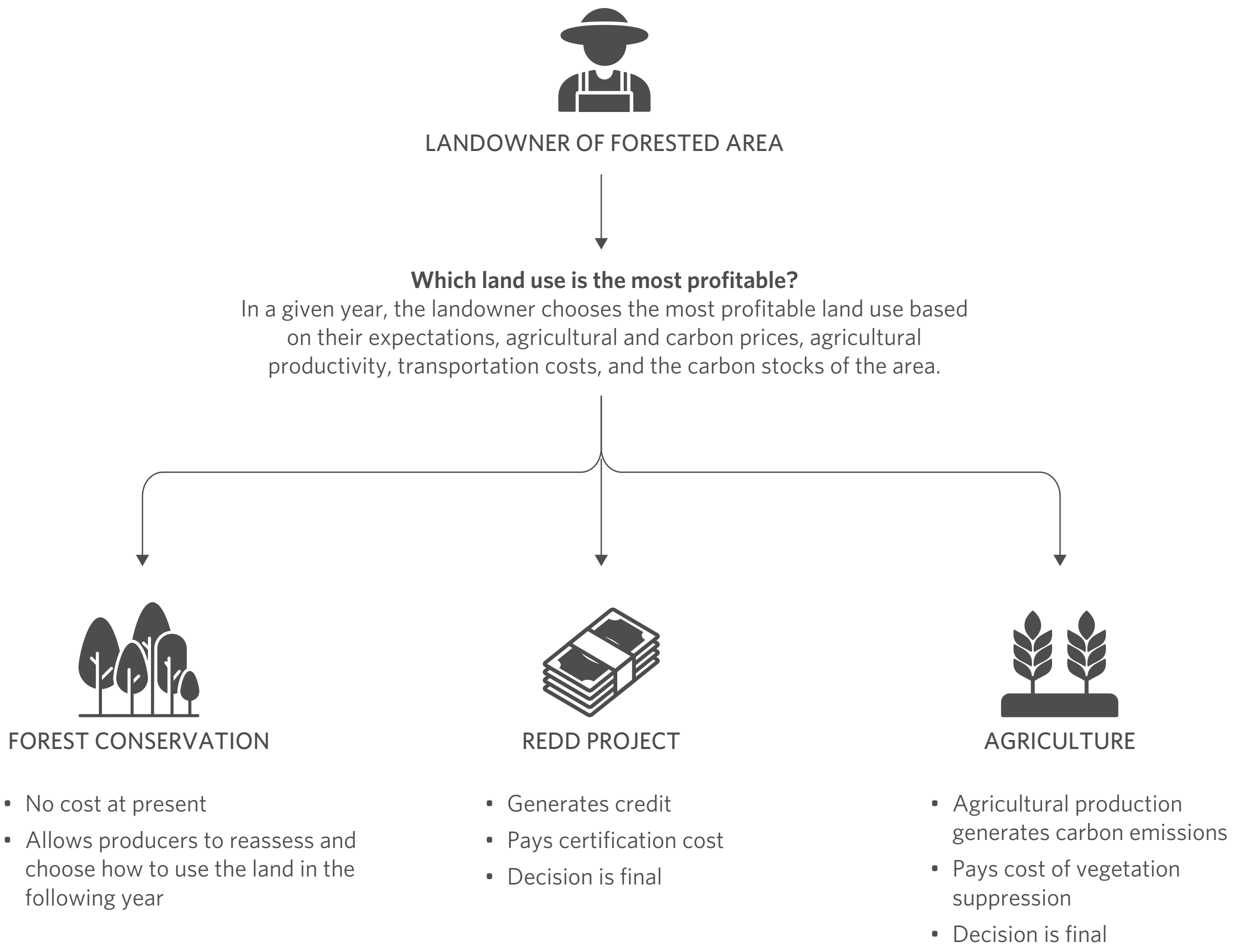
12 West, Thales A. P. et al. "Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon". *Proceedings of the National Academy of Sciences* 117, no. 39 (2020): 24188-24194. bit.ly/4jhFlEr.

Alternative Methodology for Analyzing the Effectiveness of REDD Projects

Deforestation is a complex phenomenon, making its projection a challenging task. New models have been developed to investigate land use dynamics, integrating statistical, economic, and spatial analyses. Using and adapting these new techniques, **researchers at CPI/PUC-RIO have developed an innovative methodology to assess the risk of deforestation and the additionality of carbon credits in REDD projects.**

This methodology enables the assessment of deforestation risk within private properties in the Amazon, offering a more comprehensive view than current REDD project methodologies, which are mainly based on statistical and spatial techniques. Researchers added an economic component to the analysis to understand what the most profitable land use for a given area in the Amazon would be. They then estimated the probability of a property being deforested, considering current and projected economic incentives. Economic considerations include agricultural and carbon prices, transportation costs, agricultural productivity, and carbon stocks.

Figure 1. Proposed Methodology



Source: *CPI/PUC-RIO, 2025*

The model, outlined in Figure 1, assumes that landowners of a forested area can choose one of the following uses for their property each year: standing forest, REDD, or agriculture. Landowners make decisions according to the most profitable use for their particular property, which depends on agricultural and carbon prices, transportation costs, agricultural productivity, and carbon stocks. If owners choose agriculture or REDD, they will incur a transition cost for their use: land clearing costs in the case of agriculture and certification costs in the case of REDD. In both cases, the choice is final, meaning that the owners cannot make changes throughout the period of the contract.[13] However, if the owners choose to leave their forests untouched, they pay no cost in the current year and can decide what use to make in the following period, according to current and expected prices.

Among the current criticisms of the methodologies used to estimate baselines and emissions avoided by REDD projects, the possibility of manipulating time windows and reference regions to maximize credit generation stands out.[14] The proposed methodology is shielded from these issues, since the model is estimated over a fixed period: from 2010 (the year in which REDD projects began to gain traction in Brazil) to the most recent year with available data.

Additionally, the proposed model uses all properties that are both legally and economically eligible to participate in this type of project, avoiding the comparison of regions with higher or lower levels of deforestation.[15] Although the Amazon is a vast and heterogeneous region, the model has components capable of capturing the regional effects that influence deforestation decisions. Thus, even with a large sample of more than 13,000 properties, it is possible to identify local issues that affect land use choices (for details, see the Methodology section). The choice of a large sample, which includes properties that have not been exposed to REDD activities provides additional advantages, as it allows for land use predictions based on data observed in both control units (properties eligible to participate in REDD projects) and treatment units (properties participating in REDD projects).

Another relevant feature of the proposed methodology is that, because it is an economic model, it automatically calculates the opportunity cost of deforestation, indicating the most profitable use for a property in each scenario of interest. It is important to highlight that this modeling is dynamic, which means that the analysis incorporates future revenues, trends, and economic effects, thus allowing for a more in-depth assessment of the risks of deforestation.[16] Finally, by adopting the presented approach, which is applicable to any property interested in selling conservation carbon credits, this methodology circumvents standardization and inconsistency problems observed in current methodologies, bringing more confidence to the structuring of REDD projects and supporting the evolution of this market.

13 This feature of the model is motivated by the fact that REDD contracts are generally long-term commitments of 30 years or more. In addition, there is a restriction in these projects that requires the area to be forested for at least 10 years, which rules out the possibility of transition from agriculture to forest for REDD purposes.

14 West, Thales A.P, Barbara Bomfim, and Barbara K. Haya. "Methodological issues with deforestation baselines compromise the integrity of carbon offsets from REDD+". *Global Environmental Change* 87 (2024). bit.ly/40MUy9z.

15 All properties in the Amazon that were registered in the Land Management System (SIGEF) database and had forest cover above 80% in 2010 were selected. SIGEF was chosen because the database serves as a *proxy* for strong property rights, since REDD projects require proof of land ownership.

16 Araujo, Rafael, Francisco Costa, and Marcelo Sant'Anna. "Efficient Conservation of the Brazilian Amazon: Estimates from a Dynamic Model". *The Review of Economic Studies* (2025). bit.ly/3UrqHiG.

Results

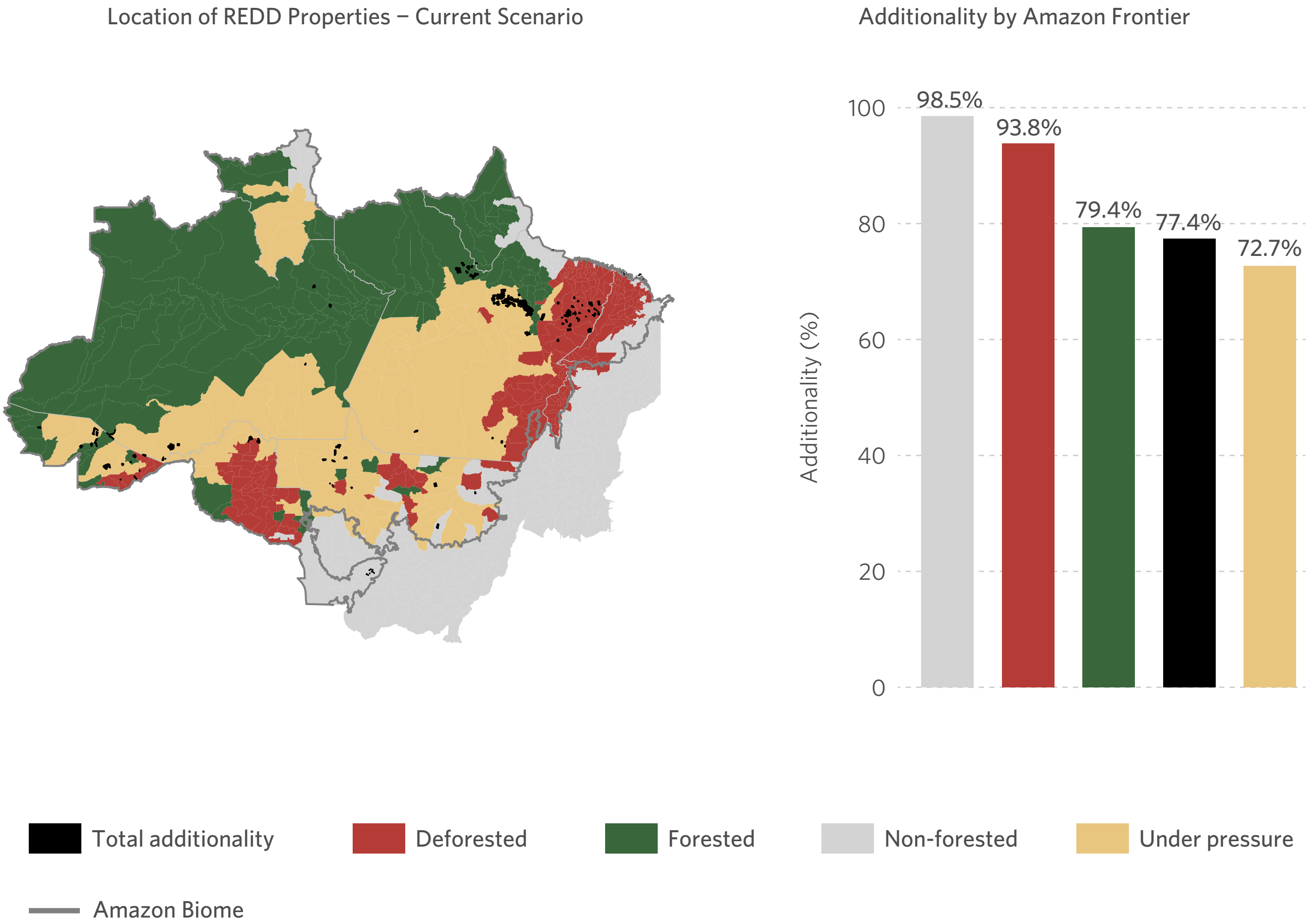
Applying this methodology to the current portfolio of REDD projects in the Amazon identifies that 77% of the carbon stock on REDD properties is additional in terms of emissions reductions.[17] In other words, in the absence of the REDD projects, most of the carbon stored in the forests on these properties would be emitted due to deforestation. By participating in these projects, the probability of deforestation inthese areas falls dramatically, avoiding the emission of 0.5 Gt of CO_2 equivalent.[18] This result suggests that the projects have played a signifcant role in forest conservation and climate mitigation. Even so, 23% of the carbon stock would have remained forested in any scenario, indicating that verifying additionality is indeed an important issue to be monitored and improved in this market.

The first panel in Figure 2 illustrates the location of properties participating in REDD projects. In this map, municipalities in the Legal Amazon were colored according to a methodology developed by Amazon Institute of People and the Environment (*Instituto do Homem e Meio Ambiente da Amazônia* - IMAZON), which classifies them according to their vegetation cover and deforestation.[19] The *non-forested* regions are composed of municipalities whose original vegetation cover was mostly savanna. The other regions correspond to municipalities whose original vegetation cover was more than 50% forest. The so-called *deforested* regions correspond to municipalities that have already lost more than 70% of their original forest, excluding protected areas. The *forested* regions, in turn, are made up of municipalities with up to 5% of their original forest cover deforested. Municipalities in the *under pressure* regions have extensive forest cover (>75% of their territory is still forest), but are undergoing rapid deforestation.[20]

When REDD properties are superimposed on the four Amazon regions described above, 98% of the carbon stock on properties located in municipalities classified as *non-forest* is additional, as shown in the second panel of Figure 2. In *deforested* municipalities, this proportion is 93%. In *forested* municipalities, this percentage drops to 79%. Finally, in municipalities *under pressure*, 72% of the carbon stock is additional. *Non-forested* and *deforested* municipalities are located in areas already consolidated by agribusiness, with lower transportation costs and better production infrastructure, which results in significant pressure to clear the remaining forest areas. One would expect additionality to be higher in municipalities *under pressure* than in *forested* municipalities, since the former are at greater risk of deforestation. This apparent inconsistency is explained in Box.

17 Data was collected in April 2023, covering all REDD projects in the Brazilian Amazon in Verra's registry.
18 Carbon dioxide equivalent (CO_2e) is a unit of measurement that represents all GHG as carbon dioxide.
19 Celentano, Danielle and Adalberto Veríssimo. *The Amazon Frontier Advancement from boom to bust.* Belém: IMAZON, 2007. bit.ly/45DoUNY.
20 Veríssimo, B. et al. *The five Amazons: basis for sustainable development of the Brazilian Amazon.* Amazon 2030, 2022. bit.ly/3Uh3xvC.

Figure 2. Location of REDD Properties and Additionality by Amazon Frontier



Source: *CPI/PUC-RIO with data from Verra (2023), IMAZON (2024), IMAFLORA (2023), MAPBIOMAS (2023), Woodwell Climate Research Center (2023), FAO-GAEZ (2023), IBGE (2023), ESALQ (2022), Ecosystem Marketplace (2023), and Copernicus ERA-5 (2023), 2025*

The Case of Portel

Several REDD projects have been implemented in Portel, Pará, a municipality classified as an *under pressure* region, with the aim of combating increasing deforestation and promoting sustainable development. However, some of these projects face challenges and controversies.

First, the region has land tenure issues, considered one of the main bottlenecks for the development of REDD projects in the Amazon. In 2023, the Public Defender's Office of the State of Pará filed a complaint of fraud involving public lands and carbon credits. According to the Public Defender's Office, Brazilian and foreign companies used public lands in the Amazon, such as rural agrarian settlements, to carry out unlawful projects that would benefit from the sale of carbon credits.[21] The agency mandated the invalidation of the projects and prohibited companies from entering the settlements.[22]

This action was prompted by a study by the World Rainforest Movement (WRM) denouncing irregularities in REDD projects in the Amazon.[23] The document highlights transparency issues regarding land ownership and potential land grabbing in Pará. In addition, the study points out that the projects in question are in regions far from the municipality's agricultural frontier, leading their developers to overestimate the emissions reductions from deforestation.

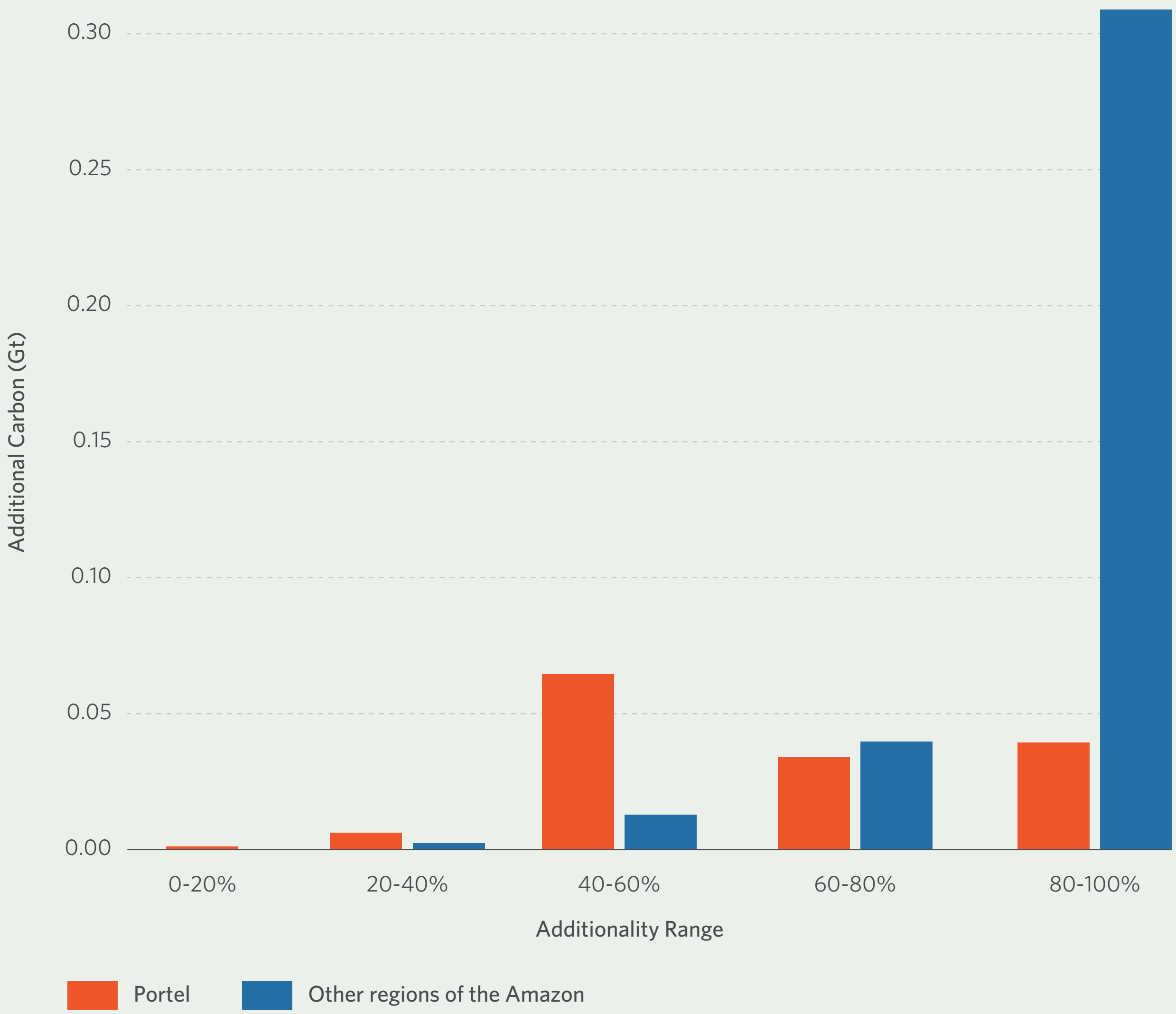
In this sense, the methodology proposed by CPI/PUC-RIO demonstrates that most properties in REDD project areas in Portel have low levels of additionality. In general, private properties in this municipality that overlap with project areas are larger than those in other regions that produce carbon credits, and they have larger carbon stocks. As a result, these areas have great potential to generate credits and profit from their sale. However, the properties in question have low agricultural productivity and high transportation costs. This makes agricultural activity in the region unviable, so the model predicts that the areas would remain forested even in the absence of carbon credit revenues. Therefore, additionality is low, as shown in Figure 3, which compares the distribution of additional carbon stocks in REDD properties in Portel (orange) with those in the rest of the Amazon (blue).

21 Rural settlements are areas designated for agrarian reform, where landless families are settled so that they can cultivate the land and have better living conditions. To learn more: Chiavari, Joana, Cristina L. Lopes, and Julia N. de Araujo. *Panorama dos Direitos de Propriedade no Brasil Rural*. Rio de Janeiro: Climate Policy Initiative, 2021. bit.ly/PanoramaDireitosDePropriedade.

22 Sinimbú, Fabíola. *Empresas de crédito de carbono são denunciadas por grilagem no Pará.* Agência Brasil. 2023. Access date: January 14, 2025. bit.ly/3PCBp3p.

23 World Rainforest Movement. *Neocolonialism in the Amazon: REDD Projects in Portel, Brazil.* 2022. bit.ly/4m857fw.

Figure 3. Additional Carbon by Additionality Range



Source: *CPI/PUC-RIO with data from Verra (2023), IMAZON (2024), IMAFLORA (2023), MAPBIOMAS (2023), Woodwell Climate Research Center (2023), FAO-GAEZ (2023), IBGE (2023), ESALQ (2022), Ecosystem Marketplace (2023), and Copernicus ERA-5 (2023), 2025*

In fact, only 57% of the carbon stock of the properties analyzed could be considered additional. Upon removing the REDD properties located in Portel from the sample, additionality in municipalities *under pressure* rises from 72% to 95%, showing that, in general, such regions face greater risks of deforestation than *forested* municipalities. Moreover, the exclusion of the Portel properties increases the overall additionality from 77% to 89%.

This demonstrates the importance of measuring the additionality of REDD projects, as there are properties with significantly low levels of additional carbon. However, this challenge can be addressed through greater oversight of project proposals in areas under lower deforestation pressure.

As seen in the case above, the regions in which REDD projects are located can provide good information about their degree of additionality. In addition, analyzing the characteristics of properties participating in REDD projects can also provide indications of what makes a given area more or less additional. This analysis indicates that properties with larger areas, high agricultural productivity, carbon stocks, and lower transportation costs tend to have the highest fractions of additional carbon—these characteristics make a property more suitable for agriculture, increasing the risk of deforestation. This information can help developers select properties that are more suitable for their projects and assist buyers in choosing projects that truly face the risk of deforestation.

Discussion

The findings presented above indicate that concerns over additionality in REDD projects are relevant, affecting about 23% of the carbon stock within participating properties. On the other hand, the fact that 77% of avoided carbon emissions result from the existence of the projects indicates that, overall, REDD projects have played an important role in forest conservation. It is also observed that the additionality of these projects tends to be higher in regions with greater deforestation pressure and lower in relatively isolated regions or areas with low agricultural productivity. Thus, one of the direct implications of this research is the need for greater oversight of project proposals located in relatively isolated regions or with low agricultural productivity. Such forest regions have high intrinsic value for the ecosystem services they provide, but they need other types of instruments to finance their conservation.[24]

Combining greater scrutiny of projects in the areas described above with what has been done in voluntary carbon markets, such as the adoption of new methodologies for calculating baselines, can contribute to the evolution and benefits of REDD projects. The adoption of more robust techniques is essential to achieve more effective results in reducing carbon emissions from deforestation. It is essential that baseline calculations be carried out by parties that do not directly benefit, as recently stipulated by Verra. Furthermore, methodologies need to be updated as new technologies and effective techniques become available.

An additional point to be made is that, although the additionality of REDD projects is not 100%, the loss due to the lack of additionality observed in these credit transactions is relatively small, especially when compared to other carbon applications. Prices for REDD projects range from US$ 5 to US$ 15 per ton of CO_2e, well below the global average for other carbon mechanisms, according to the World Bank data shown in Figure 4.[25,26] The institution monitors the status and trends of carbon pricing initiatives around the world, including instruments such as carbon taxes and emissions trading systems.[27] This shows that the for emissions avoided by REDD credits below what the global market perceives to be the price of carbon.[28] According to model simulations, REDD projects global average, additionality would rise to over 86%, further mitigating this issue.

24 Potential examples include the Tropical Forest Forever Facility (TFFF), Payment for Environmental Services (PES) mechanisms, and initiatives such as HIFOR.

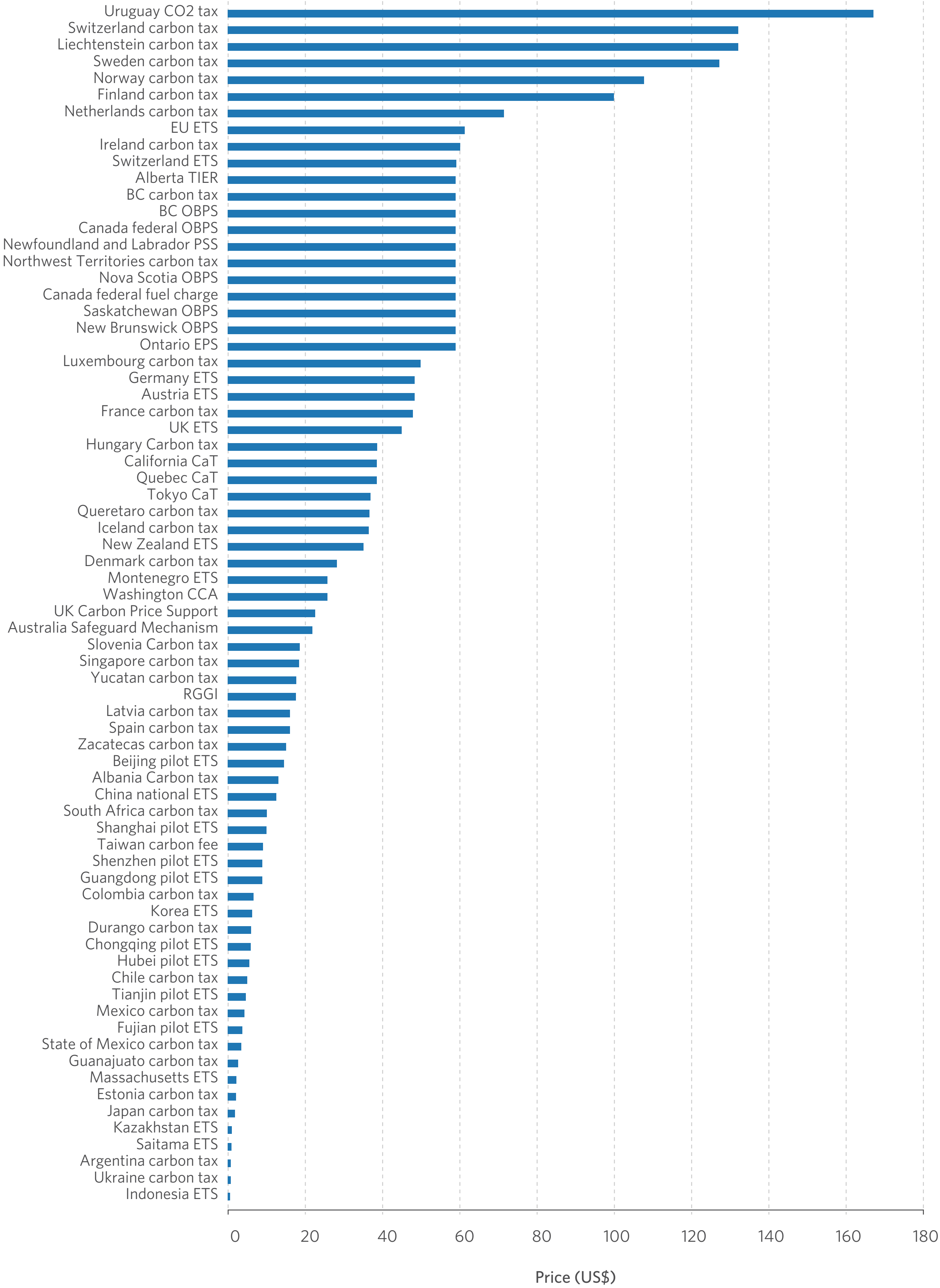
25 EM. *2024 State of the Voluntary Carbon Market (SOVCM).* 2024. Access date: January 14, 2025. bit.ly/4fZ1Ue8.

26 State of Pará Secretariat of the Environment and Sustainability. *Créditos de carbono levarão benefícios para dentro dos territórios.* 2024. Access date: February 4, 2024. bit.ly/3Ep5LUZ.

27 The World Bank monitors the status and trends of carbon pricing initiatives around the world, including instruments such as carbon taxes and emissions trading systems. See: World Bank Group. *State and Trends of Carbon Pricing Dashboard.* nd. Access date: May 10, 2025. bit.ly/3E1YCK4.

28 Considering a REDD price of US$ 10/t and 77% additionality, it is as if a buyer were paying US$ 12.98/t for a 100% additional credit, approximately one-third of the average price monitored by the World Bank.

Figure 4. Carbon Prices of Instruments Monitored by the World Bank, 2024



Source: *CPI/PUC-RIO with data from the World Bank (2024), 2025*

Thus, although additionality in REDD carbon projects does not reach 100%, the losses associated with it are relatively small. Stricter enforcement in areas less pressured by deforestation can mitigate this challenge, together with the adoption of more robust methodologies in the construction of baselines. These improvements not only strengthen the credibility of carbon markets but also enhance the potential of REDD projects to deliver NbS with greater additionality and positive climate impact.

Appendix

Methodology

This section details the methodology used to estimate the additionality of carbon credits from REDD projects.[29] The framework adopted is part of the literature on dynamic discrete choice models, in which an agent (e.g., a farmer) can choose one of several options (REDD, standing forest, or agriculture) that will maximize their profits over time, according to the economic situation (present and future prices) and their personal characteristics (e.g., property productivity). This approach allows observed data and calculated probabilities to be used to outline future scenarios, such as the optimal use of a property.

First, it is necessary to obtain the probabilities of transition from forest to agriculture and REDD activities to understand what influences land use choices. To this end, data on the transition from forest to agriculture are collected through MAPBIOMAS and data on the transition from forest to REDD are collected using data from Verra projects. The method presented here can be applied in any region of the world, provided that the necessary data is available. This allows for the estimation of the following *multinomial logit* model, which gives the probability of a property transitioning from forest to one of the three possible uses considered (REDD, forest, or agriculture):

$$\begin{aligned} transition_{m,r,t} = \alpha_j &+ \beta_1^j lat_m + \beta_2^j lon_m + \beta_3^j lat_m \cdot lon_m + \beta_4^j transportCost_m \\ &+ \beta_5^j roadDistance_m + \beta_6^j carbon_{m,t} + \beta_7^j soy_{m,t} + \beta_8^j pasture_{m,t} + \theta_r^j \\ &+ \phi_t^j + \varepsilon_{m,r,t} \end{aligned}$$

Where *lat* is the latitude of property *m*, *lon* is the longitude, *transportCost* is the transportation cost in Brazilian Real from property *m* to the nearest port, *roadDistance* is the distance to the nearest highway, while *carbon, soy*, and *pasture* are measures of carbon stock and soybean and pasture productivity, respectively, of property *m* in year *t*. *j* refers to one of the three possible uses considered, since the estimated parameters are different for each one. Finally, θ_r^j, and ϕ_t^j are fixed effects that capture specific characteristics of each immediate region *r* and each year *t*, respectively, such as local policies, climatic conditions, or economic trends, which may influence deforestation or entry into REDD projects but are not directly observed in the model. $\varepsilon_{m,r,t}$ captures the error.

Another important step in this methodology is to define the equations that describe the revenue associated with each use:

29 Learn more at: Arbache, João P. F. "Additionality in Carbon Projects: Evidence from the Brazilian Amazon". Master's thesis, PUC-RIO, 2024. bit.ly/4noiclH.

$$r_{agri} = \alpha_{agri}(p_{pt} - z_{pm})y_{mp}area_m + \overline{\alpha}_{agri} + \xi_{agri,m,t} \quad (1)$$

$$r_{forest} = \alpha_{forest}h_m area_m + \xi_{forest,m,t} \quad (2)$$

$$r_{REDD} = \alpha_{forest}h_m area_m + \alpha_{REDD}p_{REDD,t}h_m area_m + \overline{\alpha}_{REDD} + \xi_{REDD,m,t} \quad (3)$$

(1) gives the revenue associated with agriculture on a property, which will depend on its area ($area_m$), agricultural prices in year t (p_{pt}), transportation costs (z_{pm}), and the property's productivity (y_{mp}).

(2) gives the revenue from the forest, which depends only on the property's area and its carbon stock (h_m).

(3) shows the REDD revenue, which depends on the carbon stock, the area, and the carbon prices in each period ($p_{REDD,t}$).

The other elements (the α's) reflect the relationship between the revenues from a given use and the variables considered in each equation.

Here, the modeling is based on the idea that, each year, landowners choose the use that will be most profitable for their property according to the associated revenues indicated above. If they decide on agriculture or REDD projects, they will receive these revenues forever. Keeping the property as forest, however, allows them to postpone this choice to the following period.

Combining the calculated probabilities and revenues for each land use, the following equation is developed, which allows to make land use predictions:

$$log\left(\frac{p(REDD|(forest,\ \ w_{mt})|}{p(agri|forest,\ \ w_{mt}|)}\right) = \frac{r_{REDD} - r_{agri}}{1 - \rho}$$

On the left side, is the ratio between the probabilities of transitioning from forest to REDD and forest to agriculture. On the right side, there is the difference between the revenues associated with each of the two uses, brought to present value using the discount rate. After estimating this regression using observed data, the model parameters are obtained, which allow different future scenarios to be drawn up and the additionality to be measured on each property in the Amazon.

With the parameters in hand, it is possible to evaluate various future scenarios considering different prices and costs. More specifically, it is possible to calculate the probability of a property owner choosing forest, agriculture, or REDD over time, taking into account different carbon prices and participation costs, for example. Consequently, it is possible to draw a scenario in which carbon projects do not exist, so that the probability of a given property being deforested if it did not receive carbon credit revenues can be calculated. This is the baseline for this methodology, which can be contrasted with different price and cost scenarios to calculate additionality in each of them.

Here, the additionality of a property's carbon stock is given by the difference between the amount deforested in the baseline and the amount deforested in a scenario of interest (e.g., the current scenario or a scenario in which the carbon price is US$ 50/t), i.e., additionality is determined by the amount of emissions avoided due to the existence of REDD projects.

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This work is supported by a grant from Norway's International Climate and Forest Initiative (NICFI). This publication does not necessarily represent the view of our funders and partners.

The author would like to thank Juliano Assunção, Leonardo Rezende, Rafael Araujo, and Lucas Lima for their research support; Joana Chiavari, Natalie Hoover, and Gustavo Pinto for their comments and suggestions; Kirsty Taylor, Giovanna de Miranda and Camila Calado for editing and revising the text; and Meyrele Nascimento for formatting and graphic design.

Suggested citation

Arbache, João Pedro. *Carbon Credits in the Amazon: New Methodology for Assessing Project Additionality*. Rio de Janeiro: Climate Policy Initiative, 2025.

SEPTEMBER 2025

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