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Doctoral Thesis presented to the Post-Graduation Program on Production Engineering at Federal University of Minas Gerais (UFMG), as a requirement to obtain a PhD degree in Production Engineering.

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Abstract

Established in 2008 by the Brazilian Government, the Amazon Fund aims to raise results-based aid (RBA) to make non-reimbursable investments in projects to prevent, monitor and combat deforestation, as well to promote conservation and sustainable use of forests in the Amazon Biome. Although often presented as a success story, few studies have been conducted to show evidence of the effectiveness of the Amazon Fund as an RBA instrument and how much of a reduction in deforestation is within reach of its projects.The objectives of this study can be described as: (1) Look back and assess the accomplishments and shortfalls in order to draw lessons for REDD+ and RBA in Brazil and other tropical countries, examining the geographical, thematic and institutional distribution of the resources from the AF; (2) Determine the effects of the Olhos D'Água projects on deforestation, sustainable production and environmental and land-ownership compliance in the Alta Floresta municipality, estimating what would have happened without these interventions; (3) Evaluate the effect of the rural environmental registry (CAR), the larger initiative supported by AF, on the reduction of deforestation rates. To reach these objectives, this thesis was structured as 3 papers, using, respectively: procedures to structure a database and interpret the data in light of bibliographical research; an impact evaluation using the Synthetic Control method; and adapting statisticals methods widely used in epidemiological studies applied to land use policy evaluation. This research concluded that: The Amazon Fund could allocate financial resources more strategically and in activities with clear evidence of improvement for REDD+ outcomes; the project "Olhos D'Água da Amazônia I and II" played an important role in the effort of Alta Floresta to have the municipality removed from the blacklist of deforestation, at least, in a shorter period than would be in the absence of the project. The project also depict strong evidence of an increase in CAR registrations and INCRA geo-certification records and positive effects on sustainable production activities of milk and honey production, but with no effect in deforestation reduction; and, finally, the effect of CAR on the reduction of deforestation is only partially effecive, one time that the enrolled properties have reduced their deforestation rates in some property classes and time periods, but this effect has not been systematic across time and space.

Keywords: Amazon Fund, Deforestation, RBA, CAR

Resumo (Português)

Criado em 2008 pelo governo brasileiro, o Fundo Amazônia visa captar doações baseado em resultados alcançados (RBA) para investimentos não reembolsáveis em projetos de prevenção, monitoramento e combate ao desmatamento, bem como para promover a conservação e o uso sustentável das florestas no Bioma Amazônico. Embora muitas vezes apresentado como uma história de sucesso, poucos estudos foram realizados para mostrar evidências da eficácia do Fundo Amazônia como um instrumento de RBA e quantas reduções de desmatamento estão ao alcance de seus projetos. Os objetivos deste estudo podem ser descritos como: (1) Fazer um restropecto e avalir as conquistas e deficiências do FA a fim de extrair lições para REDD + e RBA no Brasil e em outros países tropicais, examinando a distribuição geográfica, temática e institucional de seus recursos; (2) Determinar o efeito dos projetos Olhos D'Água no desmatamento, na produção sustentável e na conformidade ambiental e fundiária do município de Alta Floresta, estimando o que teria acontecido sem essa intervenção; (3) Avaliar o efeito do registro ambiental rural (CAR), a maior iniciativa apoiada pelo AF, na redução das taxas de desmatamento. Para alcançar esses objetivos, esta tese foi estruturada em três artigos, um para cada objetivo especifico, utilizando, respectivamente, uma abordagem de estruturação de uma base de dados e interpretação dos resultados à luz da pesquisa bibliográfica, uma avaliação de impacto usando o método de Controle Sintético e, finalmente, adaptando métodos estatísticos amplamente usados em estudos epidemiológicos aplicados a avaliação de politicas de uso da terra. Esta pesquisa conclui que o Fundo Amazônia poderia alocar recursos financeiros mais estrategicamente e em atividades com clara evidência de melhoria para os resultados de REDD +, também conclui que o projeto "Olhos D'Água da Amazônia I e II" desempenhou um papel importante no esforço de Alta Floresta em remover o município da lista negra de desmatamento num tempo menor que na ausência do projeto. O projeto também retrata forte evidência no aumento de registros no CAR, propriedades geocertificadas no INCRA e apresenta em efeitos positivos nas atividades de produção sustentável de leite e mel, mas sem efeito na redução do desmatamento. Finalmente, conclui que a adesão ao CAR é apenas parcialmente efetiva na redução do desmatamento, uma vez que as propriedades dentro do CAR reduziram suas taxas de desmatamento em algumas classes de propriedade e períodos de tempo, mas este efeito não foi sistemático ao longo do tempo e espaço.

Palavras-chave: Fundo Amazônia, Desflorestamento, RBA, CAR

Tables - Thesis

Tables - Paper 1

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Figures - Thesis

Figures – Paper 1

Figures – Paper 2

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Summary

1 Introduction

1.1 Justification

Over the last decade, the concept of Reducing Emissions from Deforestation and Forest Degradation (REDD+) has moved away from an initially strong emphasis on market instruments for offsetting carbon emissions toward a results-based funding approach. Results-based aid (RBA) has become an important instrument for channeling financial resources to forest conservation activities (Angelsen 2017; Carvalho 2012a; Turnhout et al. 2017; van der Hoff et al. 2015). Established in 2008 by the Brazilian Government, the Amazon Fund aims to raise RBA to make non-reimbursable investments in projects to prevent, monitor and combat deforestation, as well as to promote conservation and sustainable use of forests in the Amazon Biome (ENREDD MMA 2016). With over a decade of operational activity, more than USD 1 billion in donations already received, and hundreds of supported projects, the Brazilian Amazon Fund is currently one of the largest and most experienced RBA instruments worldwide. To illustrate its effectiveness, the Amazon Fund reports performance indicators from its projects and the historical deforestation rates in Amazon. (BNDES 2017)

Despite this dominance, the effectiveness of RBA has often been challenged by scholars. Many empirical studies of development aid have identified problems with unsustainability of desirable effects, occurrences of undesired effects and unintended behaviors that obstruct the performance of RBA instruments (Oxman and Fretheim 2009; Eldridge and Palmer 2009). Scholars have reported ambiguous findings on the effectiveness of forest conservation aid (Restivo, Shandra, and Sommer 2018; Bare, Kauffman, and Miller 2015), suggesting that the relation between aid and results is indirect and much more complex in reality (Paul 2015). According to van der Hoff, Rajão, and Leroy (2018), the unclear relations between financial donations, 'project performance' and deforestation rates underlie discursive tensions between donor and recipient countries related to the Amazon Fund. Yet, studies that focus on intermediate stages of development aid, such as the redistribution of financial resources intermediary organizations (e.g. Amazon Fund), remain absent.

This thesis *"The Amazon Fund 10 years later: resource distribution and effects of REDD+ in the Brazilian Amazon"* aims to enhance our understanding of these intermediary stages between aind providers and aid users. For this, this study looks back and assess the accomplishments and shortfalls of the Amazon Fund in order to draw lessons for REDD+ and RBA in Brazil and other tropical countries, examining the geographical, thematic and institutional distribution of its resources.

In a complementary manner, aiming to evaluate Amazon Fund projects at a local level, this study analyses 2 of 12 projects formally reported as having been concluded by the Amazon Fund as of December 2017. The 2 projects can be viewed as a two-phase project and is analyzed as such. The initial analysis (Olhos D'Água da Amazonia Projects Phase I and Phase II) is the largest initiative supported by the Amazon Fund for a municipality, and it represents a special intervention as it was implemented by a municipal government with a rural location and economy historically based on agriculture, livestock, mining and logging.

Finally, this thesis aims evaluate the effect of the rural environmental registry (CAR), the larger initiative supported by AF, on the reduction of deforestation rates. The AF commited 17.1% of its funds towards to projects aiming the implementation of CAR, and 8.8% for projects from environmental secretariats to build capacity to implement CAR as well as other environmental policies.

1.2 Thesis organization

In order to answer the questions and objectives of this research, this thesis is structured in six chapters. The first two chapters, *Introduction* and *Context and Literature Review,* are based on bibliographical research; the third, fourth and fifth chapters present the *Results*, structured as 3 papers; and, finally, the sixth chapter, *Thesis Conclusion,* is presented. The content and purpose of each of the topics involved are described below and presented in Figure 1.

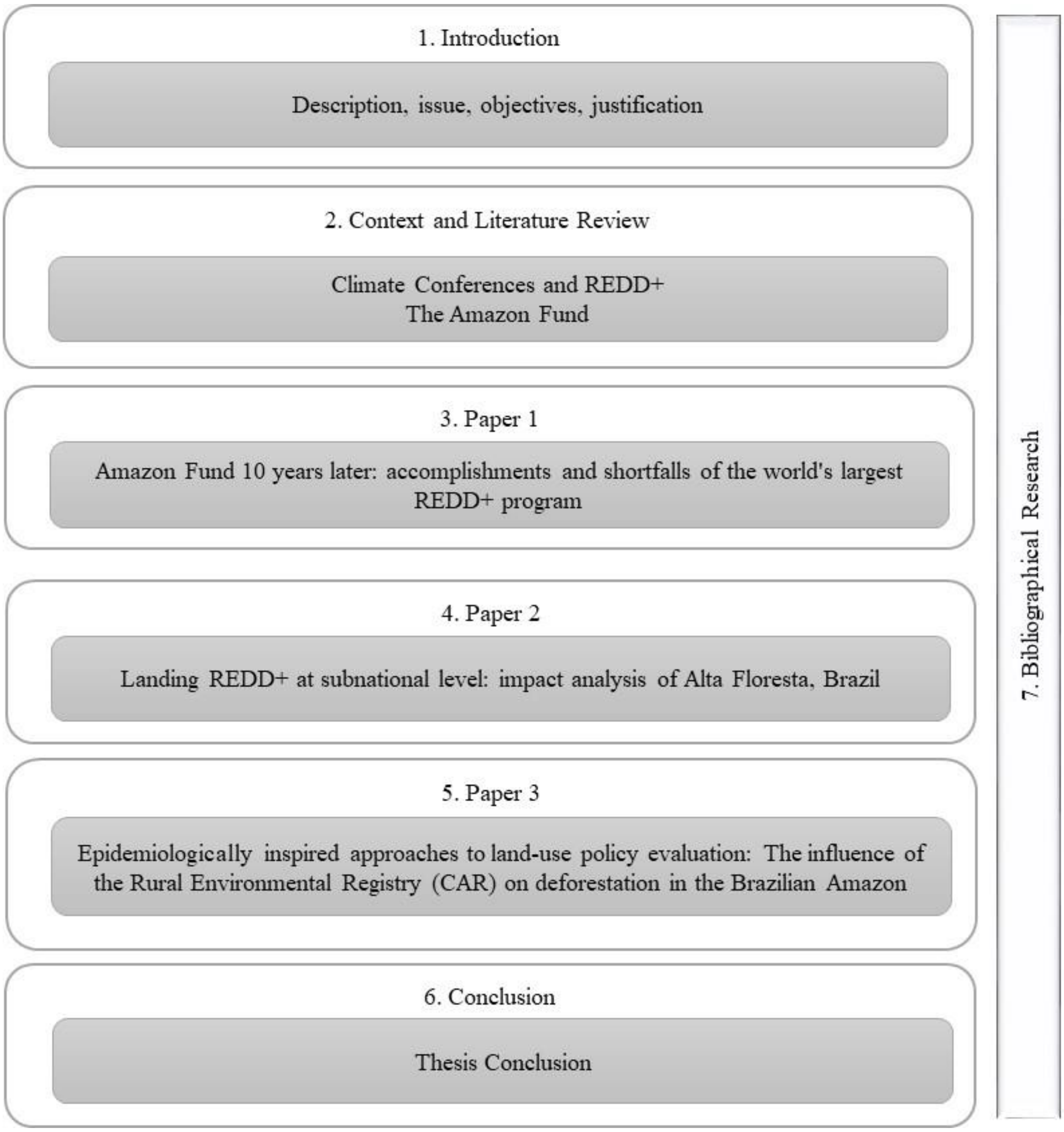


Figure 1 Thesis structure

The First Chapter – Introduction: a discussion of the description, relevance and justification of the theme, the problems and objectives of the research, and the structure of the work.

The Second Chapter – Context and Literature Review: contextualizes the basic concepts necessary for research and understanding of the work through the topics of Global Climate Conferences, REDD + and the creation of the Amazon Fund.

The Third, Fourth and Fifth Chapters – The results of 3 papers regarding the objectives of the study: *"Amazon Fund 10 years later: accomplishments and shortfalls of the world's* *largest REDD+ program"* addresses the objective of revealing which stakeholders, activities and locations have received support and considers likely impacts; *"Landing REDD+ at subnational level: impact analysis of Alta Floresta, Brazil"* addresses the objective of determining the effects of the Olhos D'Água projects in the munipality of Alta Floresta, estimating what would have happened without this intervention; and,*" Epidemiologically inspired approaches to land-use policy evaluation: The influence of the Rural Environmental Registry (CAR) on deforestation in the Brazilian Amazon"* addresses the objective of evaluate the effect of CAR on the reduction of deforestation rates.

The Sixth Chapter – Conclusion: relates the objectives proposed in this work with the results achieved, limitations and suggestions of future research, and general conclusions.

2 Contextualization and Literature Review

2.1 The Global Climate Conferences and REDD+

In response to worsening environmental conditions, such as the depletion of the ozone layer and global warming at alarming levels, the Conference on Environment and Development (UNCED) was created in 1983 by the United Nations, culminating with its publication "Our Common Future" (Brundtland et al. 1987). This consolidated the concept of sustainable development as: "*…development that meets the needs of the present without compromising the ability of future generations to meet their own needs".*

The United Nations Environment Programme (UNEP) and the Word Meteorogical Organization (WMO) established in 1988 the IPCC – Intergovernmental Panel on Climate Change aiming with the mission of evaluating research, interpreting it, and gathering all relevant information about climate change, both technical and socioeconomic, into comprehensive, easily understood and accessible reports. Since its foundation, IPCC credibility has been challenged by scholars because, despite the warming of the climate system be unequivocal, it is not possible to attribute all, or even a large part, of the observed global mean warming to the enhanced greenhouse effect on the basis of observational data currently available (Newman 2017).

The 1992 UNCED conference, known as the "RIO-92 Earth Conference" and attended by more than 172 nations and 116 presidents or government leaders, resulted in three conventions with binding legal treaties on: Biological Diversity (UNCBD 2015), Combating Desertification (UNCCD 2015) and Climate Change (UNFCCC 2015a).

The UNFCCC treaty, signed at the RIO-92 conference by almost every country in the world, aims to stabilize the concentration of greenhouse gases in the atmosphere at levels that prevent global warming. The scientific community believes that, if emissions of these gases continue to grow at the current rate, the rise in global temperatures will result in irreparable damage to the environment. The main principle underlying the UNFCCC is common but differentiated responsibility; that is, as the current concentration of greenhouse gases in the atmosphere is a consequence, for the most part, of emissions by industrialized countries in the past, each country has a different responsibility (placing an end point at the controversial proposal of zero development equally by all nations disregarding the historical responsibilities of each party as discussed since 1968) (Meadows et al. 1972; UN Stockholm Report 1972). For the division of responsibilities, the countries were divided into different blocks: Annex I, composed of industrialized developed countries that must return individually or jointly to their 1990 levels of anthropogenic emissions of carbon dioxide and other greenhouse gases, or otherwise buy carbon credits from developing countries; Annex II, composed of developed countries that must pay the costs to developing countries; and non-Annex countries, developing countries that do not have to present emission targets but have mitigation obligations (UNFCCC 2015a).

The treaty of the UNFCCC did not set protocols with emission targets per country; for this, the members have met periodically at the Conferences of the Parties (COPs) since COP-1 in Berlin in 1995 (UNFCCC 2015a). The Kyoto Protocol, signed at COP-3 in Kyoto in 1997, defines a 5.2% reduction of greenhouse gas emissions in reference to 1990 values in the period from 2008 to 2012, later extended to 2020 by the Doha amendment. The validity of the protocol was conditional on the ratification of 55 countries, which happened only in 2005 ("Kyoto Protocol" 2015). At COP-5 in Bonn 1999, discussions began on the impact of human activities and the role played by land use, land-use change and forestry (LULUCF) in reducing greenhouse gas emissions. The issues of emissions from tropical deforestation and changes in land use were officially accepted in the discussions at COP-11 in Montreal in 2005 (Carvalho 2011; Moutinho et al. 2005). Several scholars pointed out that the release of cabon through deforestation and forest degradation are the second biggest source of greenhouse gas emissions (Avissar and Werth 2005; Holly K. Gibbs et al. 2007; Soares-Filho et al. 2010; van der Werf et al. 2009). The concept of Reducing Emissions from Deforestation and Forest Degradation (REDD)—known as REDD+ when encompassing a broad suite of efforts to conserve forests, sustainably manage forests, and enhance forest-carbon stocks within developing countries—was consolidated at COP-12 in Nairobi in 2006, in COP-13 in Bali in 2007 and at COP-14 in Poznan 2008 (Gibbs et al. 2007; UNFCCC 2015b).

In this context, the next section explains the origin, stabilization and governance of the Amazon Fund, how it understands the RBF concept and reports its results, and a literature review with the main studies carried out on it.

2.2 Origin of the Amazon Fund

Influenced by the increase in international voluntary donations to finance incipient REDD initiatives, the Brazilian Government established the Amazon Fund in 2008, aiming to raise RBF to make non-reimbursable investments in projects to prevent, monitor and combat deforestation, as well to promote conservation and sustainable use of forests in the Amazon Biome (ENREDD MMA 2016). COP-19 in Warsaw in 2013, COP-20 in Lima in 2014 and COP-21 in Paris in 2015 established: governance determining the minimum requirements for the national REDD+ strategies and their contributions to reducing greenhouse gas emissions; an informational hub for publishing information on results-based payments available; the UNFCCC Green Climate Fund (GCF) to finance REDD initiatives; and that developed countries should invest 100 million dollars per year in developing countries. In 2016, besides the GCF, the Amazon Fund was formally accredited to raise RBA by the Brazilian National REDD+ Strategy (ENREDD+) and its results are posted at the informational HUB to be accounted for in the Brazilian results (ENREDD MMA 2016).

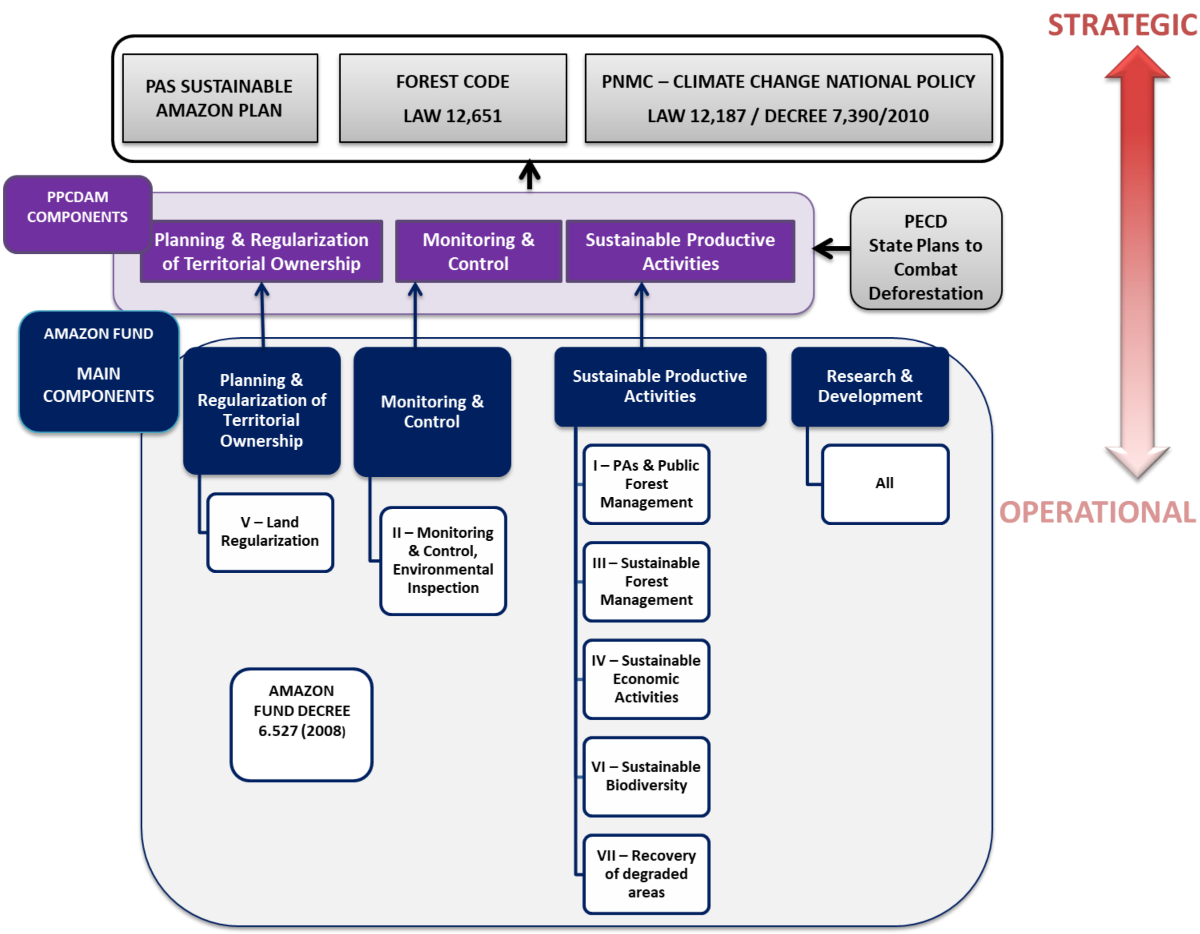


Figure 2 PPCDAm and the Amazon Fund Link

The Amazon Fund is managed by the National Bank for Socio-Economic Development (BNDES—from the acronym in Portuguese), and the commitment of financial resources from the Amazon Fund to individual projects occurs based on a set of criteria and guidelines that are updated biannually by the fund's steering committee - COFA (BNDES 2017). The 2017-2018 version of this document states fourteen minimum requirements that potential projects must meet in order to receive financial resources, some of which determine the conceptual boundaries of project activities. Firstly, projects must adhere to at least one of the thematic areas outlined in federal law (Decree n. 6527 2008), namely (1) public forest management, (2) monitoring, control and enforcement, (3) sustainable forest management, (4) sustainable economic activities, (5) Ecological-Economic Zoning, (6) conservation and sustainable use of biodiversity, and (7) regeneration of deforested areas. Secondly, projects must demonstrate coherence with Brazilian environmental and forest policies, most notably the national Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) and its manifestations in state governments (PPCDs). These plans establish three core categories, namely (1) monitoring and control, (2) land title regulation, and (3) sustainable production activities, which also constitute the basis for the assessment of project proposals (BNDES, 2017). Thirdly, projects must demonstrate coherence with ENREDD+, which incorporates the implementation of PPCDAm and compliance with the Brazilian Forest Code, National Climate Change Policy (PNMC) and Sustainable Amazon Plan (PAS). Finally, projects must respect the principle of financial additionality with respect to public environmental budgets as well as other forms of finance. In light of these criteria and guidelines, any organization may submit a project proposal to BNDES to apply for financial resources (Figure 2).

Regarding the RBA concept, the limit of donations that can be received annually is set based on criteria and guidelines certified by the fund's technical committee (CFTA). The reduction is calculated based on the difference between the intended deforestation rate and a baseline with a 10-year historical average, multiplied by the quantity of carbon in biomass (reference value of 132.3 metric tons of carbon per Hectare) and converted from C to CO^2 by a fixed factor (reference value of 44/12). The baseline with a 10-year historical average is updated every 5 years (Figure 3) and the amount is monetized at 5 USD per ton of CO^2.

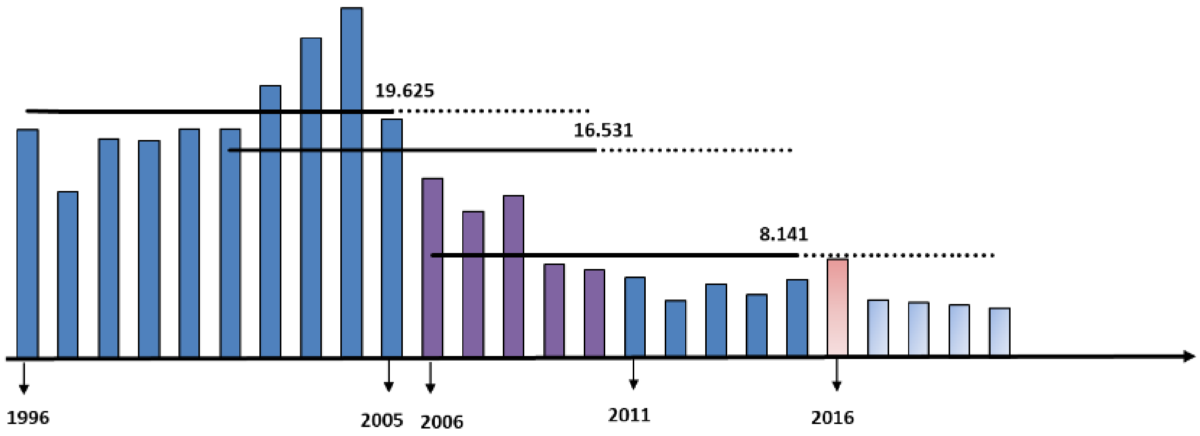


Figure 3. Brazilian Amazon deforestation rates

Source: Prodes-INPE (2017)

These calculations are represented by the following equations:

$$Reductions_{ton\ CO^2} = \left(def_{10\ years\ historical\ average} - def_{year\ intended}\right) \times 132.3 \times (44/12)$$

$$Maximum\ of\ Donations_{\ USD} = \ Reductions_{\ ton\ CO^2} \times 5\ USD$$

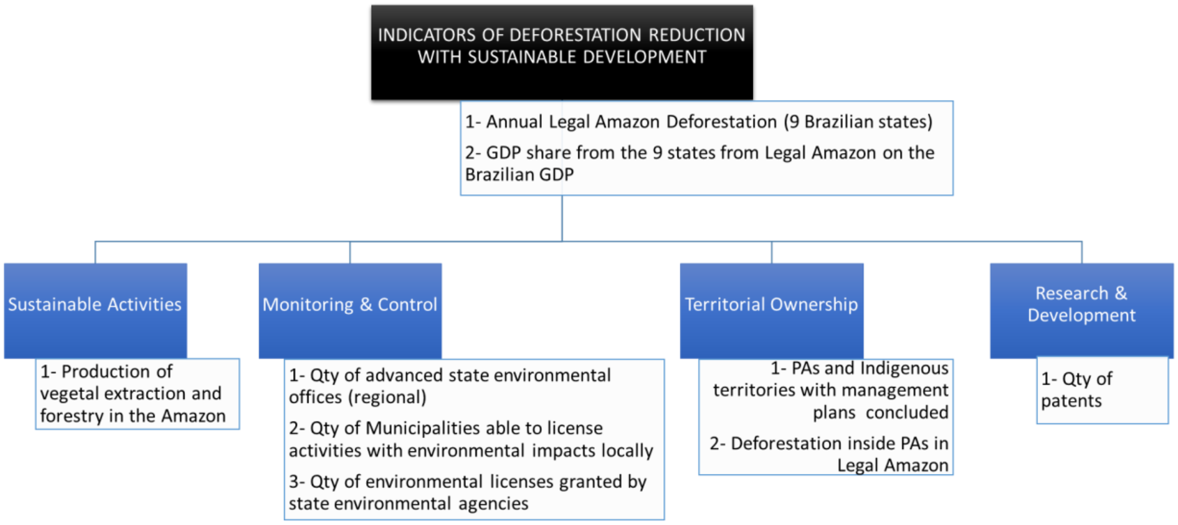
Where *def* stands for the deforestation measured by Prodes, a satellite-based monitoring system from the National Institute of Spatial Research (INPE) that provides the official rates of deforestation for the Brazilian Amazon. E.g., The maximum donation that Amazon Fund could receive for 2016, when 7,893 km2 were deforested, used the 10-year average for deforestation from 2006 to 2015 where 8,141 Km2 were deforested (see Figure 3). This calculation is displayed below, where the reduction for 2016 is:

$$(814{,}100 - 789{,}300) \times 132.3 \times \left(\frac{44}{12}\right) = 12{,}030{,}480\ ton\ CO2$$

And the limit of donations that the Amazon Fund could receive for 2016 is:

$$12{,}030{,}480\ \times 5 = U\$\ 60{,}152{,}400.00\ USD$$

For the monitoring of its performance, the Amazon Fund reports 2 classes of indicators. The first is the Amazon Regional indicators, composed of comprehensive data related to the public policies to which the Fund aims to contribute to, as depicted in Figure 4 below:



1- Source: INPE - PRODES
2- Source: BNDES, using IBGE database processed by state statistical agencies, secretariats and Manaus Free Trade Zone superintendence (Suframa).
3- Source: BNDES, using IBGE database. (Acai, Nuts, Rubber, Oilseed, Fibers). IPCA amounts to financial projections
4, 5 e 6- Source: BNDES, using State Environment Secretariats data.

Figure 4. The Amazon Fund Regional Indicators

The second class is project performance indicators, composed of auditable data collected in the field and completed by the beneficiaries of each project. These are used to measure the efficiency and effectiveness of the project and categorized by main components, as in Table 1.

Table. 1 Amazon Fund Project Performance Indicators

MAIN COMPONTENT	PROJECT INDICATORS
Monitoring & Control	Number of strengthened environmental agencies (federal, state and municipal)
	Number of trained employees
	Number of rural properties with geo-referenced mapping carried out for joining CAR
	Area of rural properties with geo-referenced mapping carried out for CAR purposes (ha)
	Number of properties that asked to enroll in the CAR (protocol)
	Area of properties that that asked to enroll in the CAR (protocol) (ha)
	Amount disbursed to projects to combat forest fires and illegal burnings (R$)
	Number of individuals trained in fire-fighting techniques for the formation of civilian brigades
Promotion of Sustainable Productive Activities	Number of workshops and training courses
	Number of individuals trained to practice sustainable economic activities
	Number of Community organizations strengthened
	Number of small subprojects (up to R$ 100,000) supported by connected entities
	Number of medium or large subprojects supported by connected entities
	Number of properties with sustainable production projects
	Number of rural properties that received technical assistance benefits
	Forest area directly managed as a result of the project

	Units of processing of extractive family-farming products implanted
	Revenue obtained from the sale of natural products (R$ thousand)
	Individuals directly benefited by the supported activities
Planning & Regularization of Territorial Ownership	Number of protected areas
	Area of conservation units created (km²)
	Extension of protected areas with environmental management plans or strengthened territorial control (km²)
	Number of rural properties geo-referenced for land regularization purposes
	Area of rural properties geo-referenced for land regularization purposes (ha)
Research & Development	Total amount disbursed for scientific and technological research (R$ million)
	Amount disbursed to investment in research infrastructure (R$ million)
	Number of researchers and technicians involved in scientific and technological research activities residing in the Amazon Region during project execution
	Number of scientific, pedagogical or informative publications produced

In addition to these monitoring indicators, the Amazon Fund publishes in its annual activity report qualitative descriptions of results, representing main the points of view of project implementers or beneficiaries. Recently, the Fund has initiated an external evaluation of some projects carried out through agencies such as the German Society for International Cooperation (GIZ, from the acronym in German).

Van der Hoff & Rajão (2018) highlight that Brazil, through the Amazon Fund, developed an understanding of RBF as a reward for previously acheived reductions in deforestation, rather than a contractual commitment to provide further reductions that, if considered in advance, would be conditional (van der Hoff et al. 2015). According these scholars, the unclear relations between financial aid, 'project performance' and deforestation rates underlie discursive tensions between donor and recipient countries related to the Amazon Fund.

Yet, the effectiveness of RBA has often been challenged by scholars. Many empirical studies of development aid have identified problems with unsustainability of desirable effects, occurrences of undesired effects and unintended behaviors that obstruct the performance of RBA instruments (Oxman and Fretheim 2009; Eldridge and Palmer 2009) . Forstater, Nakhooda, and Watson (2013) concluded that, although the Amazon Fund was created as results-based model, it is not clear how much of a reduction in gas emmissions is within reach of their projects. These authors predicted that, when deforestation rates increased, the Amazon Fund results-based model would be questioned further; and, beyond improving reporting results to enhance fundraising potencial, they recommended developing an investment strategy to achieve fund objectives, rather than passively responding to applications received. Marcovitch and Pinsky (2014) highlighted that the creation of an effective monitoring and evaluation program is crucial to the program's success. (Lee et al. 2015) carried out a study in eight countries and depicted a causal relationship between international REDD+ finance and significant impacts on forest-related emission reductions. For Brazil, the authors showed that the decrease in deforestation since 2004 is largely attributable to government policies and enforcement, in particular, the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM), and not the Amazon Fund, although Abranches (2014) suggests that the funding has been indirectly helpful in maintaining the progress of PPCDAM.

Van der Hoff and Rajão (2018) highlight the lack of a clear link between project performance as assessed within the formal Amazon Fund mechanisms and impacts on rates of deforestation, and that donor countries, such as Norway and Gemany, are offering critical evaluations of this gap, raising institutional pressure to address it. The donors have indicated an interest in paying only for more recent results, as opposed to the achievements between 2006 and 2016 considered by the Amazon Fund, and expressed some concern that Amazon Fund objectives are not reflected in project performance indicators or independent evaluations.

Additionally, in relation to evidence of results-based effectivity, scholars have raised concerns about the amount and distribution of financial flows from the Amazon Fund to recipient organizations, stakeholders, activities and locations. Dalene (2011) depicts the overall political legitimacy, the reliable monitoring system of deforestation, and the integration of the fund with national deforestation policies as strengths of the Amazon Fund; while she criticizes that the amounts of donations raised are insufficient to combat all deforestation causes, governance does not include degradation and other biomes should be considered. Boucher, Roquemore, & Fitzhugh (2013) argue that deforestation reductions are due to several factors, such as government policies and enforcement actions by prosecutors at both federal and state levels, the incentives created by Norway's pledge of up to $1 billion to the Amazon Fund, the strong and concerted pressure exerted by Brazilian civil society on the government and soy and beef industries, and the positive response of those industries, resulting in the 2006 soy and 2009 beef moratoria. Although highlighting that the Amazon Fund received international endorsement that enhanced domestic accountability provided by the management of BNDES, Birdsall, Savedoff, & Seymour (2014) state that Amazon Fund performance outpaced funds available for payments and that the main agreement linked transfers at the pace of financial need, thereby failing to represent a fair results-based payment system. These authors expressed concern that maintaining progress on deforestation reduction will be more difficult over time, questioning the sustainability of Amazon Fund, and concluded with the issue of whether the selected projects are really the best strategy for emissions reductions.

In one of the rare quantitative studies on the subject, De Alencastro Bouchardet (2016), through spatial modeling using covariates of prices of cattle, soy and corn, the Amazon Fund disbursements to the municipalities, and the “fixed effects”, concludes that 6,400 Km2 of deforestation in the Brazilian Amazon was avoided through Amazon Fund investments between 2010 and 2013 and that, in the absence of these disbursements, deforestation would be 29% higher in the same period (de Alencastro Bouchardet 2016; de Alencastro Bouchardet, Alves Porsse, and Timofeiczyk Junior 2017). These results have been challenged by scholars, since Brazil spent US$ 1 billion/year on forest conservation policies only at the federal level since 2004 (Cunha et al. 2016), Brazilian rural credit with reduced interest available for supporting agriculture in the 2012/2013 harvest was USD 61.6 billion (MAPA 2018), and the Brazilian GDP for 2013 was USD 2.4 trillion (World Bank 2014) Between 2010 and 2017, the accumulated disbursements reported by the Amazon Fund were only USD 329 million, a insignificant fraction compared with the former amounts; Despite these investments, other sources of funding beyond the Amazon Fund have supported forest conservation initiatives in the same regions, such as the World Bank and NGOs. Public Policies and iniciatives supported by all levels of government carried out also overlapped the Amazon Fund initiative. For an effective evaluation of an comprehensive environmental program that supports a myriad of different stakeholders, activities and regions as Amazon Fund, Correa et al. (2018) highlighted the necessity of carry out individual impact evaluations of its supported projects to eliminate plausive rival interpretations due to diversity of confounding factors that also affect the outcomes. .

This study is positioned precisely in these gaps, and, in order to reach its objectives, this thesis was structured as 3 papers, as follow in the next section.

3 Amazon Fund 10 years later: accomplishments and shortfalls of the world's largest REDD+ program

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Abstract: The Amazon Fund (AF), created in 2008 by the Brazilian government, is the world's largest REDD+ program based on Results-Based Aid (RBA). By the end of 2017 the AF received USD 1.2 billion, mostly from the Norwegian (93.7%) and German (5.6%) governments, and committed USD 667.3 million to support the 96 projects from governmental and non-governmental organizations. As the AF completes 10 years it is important to look back and assess the accomplishments and shortfalls in order to draw lessons for REDD+ and RBA in Brazil and other tropical countries. This paper examines the geographical, thematic and institutional distribution of the resources from the AF. With this aim this study complied a dataset and estimated the temporal distribution per project, municipality, main component and activity of the AF resources based on spatially explicit data and the individual project reports. State governments concentrated most of the committed resources (38.4%), followed by NGOs (36.1%) and the Federal Government (21%). While it is important for the AF to support the strengthening of governmental bodies, there is evidence that the AF resources replaced rather than complemented Brazilian taxpayer fund at federal level. This is particularly evident in relation to funds for law enforcement and satellite monitoring. Amongst the different activities supported by the AF, the implementation of the environmental registry (CAR) received by far most of the resources (17.1%), followed by Satellite Monitoring (11.4%). While CAR has the potential to provide the basis for stronger environmental governance, the lack of effects of the registry during its initial years should raise some concerns (Costa, Rajão et al. 2018). The analysis of the geographical distribution of the AF projects suggests some concentration of resources where the agricultural frontier advances towards the forest due activities aiming develop sustainable production and the strengthening of PA's, IT's, while activities aiming private properties in activities as agriculture or livestock intensifications were left out. This article concludes by pointing to the need to develop a science-based strategy for investing the increasingly scarce resources of the AF in order to secure stronger results on the long term. It also shows the importance of improving transparency mechanisms in order to avoid the replacement of public funds by AF funds, and ensure the financial additionality of donations

Keywords: REDD+; Amazon Fund; Results-Based Aid; resource distribution

1-Introduction

International allocation of funds to activities intended to aid forest conservation – directly or indirectly – is said to be a "highly cost-effective way of reducing greenhouse gas emissions" (Stern 2006). Among many types of financial mechanisms for pursuing this approach, Results-Based Aid (RBA) for Reducing Emissions from Deforestation and Forest Degradation (REDD, or REDD+ for a broader suite of activities) has become an important instrument for channeling financial resources to forest conservation activities (Turnhout, Gupta et al. 2016, Angelsen 2017). The success of RBA instruments for REDD+ stems from political controversies related to initial REDD+ proposals that favored offset-based markets (Den Besten, Arts et al. 2014). Particularly the Brazilian government has been known to challenge the use of markets on the basis of sovereignty concerns (Carvalho 2012, Van der Hoff, Rajão et al. 2015). Instead, Brazil created the Amazon Fund in 2008 and thereby gave rise to one of the largest results-based instruments related to the forest in the world (Wolosin, Breitfeller et al. 2016). Similar developments have also occurred in international forest governance debates as the Green Climate Fund became the central financial instrument for REDD+ (Voigt and Ferreira 2015). Furthermore, there is emerging evidence that biodiversity conservation aid has been effective (Miller, Agrawal et al. 2013). These developments testify that RBA approaches dominate in REDD+ and forest governance debates.

Despite this dominance, the effectiveness of RBA has often been challenged by scholars. Many empirical studies of development aid have identified problems with unsustainability of desirable effects, occurrences of undesired effects and unintended behaviors that obstruct the performance of RBA instruments (Eldridge and Palmer 2009, Oxman and Fretheim 2009). Scholars have reported ambiguous findings on the effectiveness of forest conservation aid (Bare, Kauffman et al. 2015, Restivo, Shandra et al. 2018), suggesting that the relation between aid and results is indirect and much more complex in reality (Paul 2015). According to Van der Hoff, Rajão et al. (2018), the unclear relations between financial donations, 'project performance' and deforestation rates underlie discursive tensions between donor and recipient countries related to the Amazon Fund. Yet, studies that focus on intermediate stages of development aid, such as the redistribution of financial resources intermediary organizations (e.g. Amazon Fund), remain absent. This research paper aims to enhance our understanding of these intermediary stages.

As the AF completes 10 years this study aims to look back and assess the accomplishments and shortfalls in order to draw lessons for REDD+ and RBA in Brazil and other tropical countries, examining the geographical, thematic and institutional distribution of the resources from the AF.

Such an analysis exposes the underlying rationales (or 'theory of change') adopted for redistributing financial resources, which is useful for identifying the main factors for successful or failing forest conservation aid. The remainder of this paper proceeds as follows. Section 2 reviews the literature on related resource allocations, including the theories of change, criteria for resource allocation, benefit-sharing mechanisms and impacts. Section 3 then outlines our approach and Section 4 presents data about the distribution of Amazon Fund resources. Section 5 concludes with our main findings and their implications for impact and policy making.

2. Aid effectiveness and the complex relations between service providers and service users

Conservation aid has been a relatively recent trend in the broader context of development aid and has mainly targeted biodiversity conservation (Miller 2014) and deforestation reduction. Although this aid could come in many forms, RBA has become an increasingly appealing approach for dealing with the "principal-agent problem", in which the "principal" (e.g. donor organization) provides financial (or technical) aid to an "agent" (e.g. recipient organization) conditional on behavioral change, service provision or policy reform by the latter (Eichler 2006, Eldridge and Palmer 2009). In practice, RBA captures a broad variation of conceptualizations that combines "two sets of terms: conditional/output-based/performance-based/results-based and aid/funding/financing/lending/payment/incentives/contracting" (Angelsen 2017).

As mentioned in the introduction, however, the effectiveness of this approach in attaining these objectives has been abundantly challenged in scientific literature, often arguing that empirical evidence is either lacking or points to contradictory effects (e.g. Eldridge and Palmer 2009). Similar to development aid (Tierney, Nielson et al. 2011), evidence for the effectiveness of forest conservation aid is ambiguous. Restivo, Shandra et al. (2018) demonstrated that more bilateral aid from the United States Agency for International Development (USAID) has a lowering effect on forest loss, instead pointing at other factors like agricultural and forestry exports as drivers of forest loss. By contrast, Hermanrud and de Soysa (2017) reported that forest conservation aid from Norway´s International Forest and Climate Initiative (NICFI), one of the largest aid initiatives in the world and the main donor to the Amazon Fund, has had no effect on forest degradation. The latter argument seems more common in scientific studies. Matthew, Craig et al. (2015), for example, argue that forest conservation aid in sub-Saharan Africa "is not associated with reduced deforestation rates at the national scale" and even claim that short-term impacts had negative effects. These scholars, however, acknowledge that the relations between aid and results are complex and therefore difficult to analyze.

The problem with evaluating the effectiveness of RBA initiatives is that the relations between service users (aid providers) and service providers (aid users) are much more complex than the principal-agent model suggests. According to Paul (2015), the contracted agency relationship is often one between donor organization and a recipient organization or ministry, whereas results may come from other organizations that ultimately spend the financial resources from these donations but have no direct relation with the donor organization (i.e. non-contracted agency relation). The 96 projects that receive financial support from the Brazilian Amazon Fund, for example, have a direct relation with the Brazilian Development Bank (BNDES) and are only indirectly related to the Norwegian or German donor organizations that provide forest conservation aid (Dalene 2011, Boucher, Roquemore et al. 2013, Birdsall, Savedoff et al. 2014, BNDES 2018). These indirect relations are partially responsible for many of the conflicts on what constitutes results, since they may involve very diverging approaches to performance indicators (Van der Hoff, Rajão et al. 2018). Addressing these conflicts may imply the development of new approaches to aid effectiveness that account for the complex relations of RBA for REDD+.

A starting point for such work may be found in the literature on the distribution of REDD+ benefits. Many scholars have highlighted the issues of equitable sharing of net benefits from REDD+ projects (e.g. Luttrell, Loft et al. 2013, Wong, Loft et al. 2017). Benefit distribution is an important component in any 'theory of change' concerning the basis for having positive expectations about attainment of desired objectives. Any such theory should lay out "who needs to be involved, whose interests are at stake, and the expected co-benefits and required safeguards" (Putz and Romero 2012). Yet rigorous analysis and even merely comprehensive evaluations of net benefits and their distribution are scarce, in part because of exactly how decisions are made about distributions of resources within and across REDD+ projects (Van der Hoff, Rajão et al. 2018). More generally, there is no consensus among scholars about the most effective REDD+ target activities, the most relevant stakeholders, or the most important geographical regions, because these questions are context-specific (Brockhaus, Korhonen-Kurki et al. 2017, Korhonen-Kurki, Brockhaus et al. 2018).

Concerning target activities, literature emphasizes the importance of addressing drivers of deforestation and forest degradation. Weatherley-Singh and Gupta (2015), for example, find that REDD+ activities are somewhat responsive to both some direct drivers such as forest fires, illegal logging and structural drivers such as changes in land tenure and land-use planning. Yet they argue that not all drivers are considered as most schemes do not address cattle ranching, corruption, roadbuilding and or commodities demands (see also Dunlop and Corbera 2016, Busch and Ferretti-Gallon 2017). A possible response is to make transfers conditional upon desired results, as within well-implemented payments for ecoservices (PES) approaches (Pham, Brockhaus et al. 2013). Some results-based instruments endeavor to be conditional in that way. For instance, donations of financial resources to the Brazilian Amazon Fund are in principle based upon historical results in deforestation reduction, as a form of compensation intended to be reinvested in policies and practices to further reduce deforestation (Van der Hoff, Rajão et al. 2018). Scholars have noted that such conditioning could require environmental additionality, that is, provide more ecoservices than without the activities (Chiroleu-Assouline, Poudou et al. 2018, Cordero Salas, Roe et al. 2018). This may lead to the response that REDD+ funds should be 'financially additional', beyond already planned funding (Dutschke and Michaelowa 2006). Conditioning on environmental additionality could exclude 'forest stewards' in what currently are low-deforestation areas (Luttrell, Loft et al. 2013), unless they are viewed as holding off threats.

Concerning any sort of distribution across stakeholders based on REDD+ activities, Luttrell, Loft et al. (2013) distinguish a number of possible rationales for the distribution of REDD+ benefits. They have emphasized: (1) actors with legal rights; (2) actors achieving reductions in emissions; (3) low-emitting forest stewards; (4) actors incurring the costs of REDD+ implementation; (5) effective facilitators of REDD+ implementation; and (6) the poorest actors. They note great variation in how implementing countries apply these rationales, including as a function of context, project design and the stakeholders involved (see also Pham, Brockhaus et al. 2013).

Some scholars find "equity can have significant positive feedback on program outcomes and legitimacy over the longer term" (Pham, Brockhaus et al. 2013, Dunlop and Corbera 2016, Wong, Loft et al. 2017). According to Vatn and Vedeld (2013), market-based approaches were found to be the most problematic among governance structures, since they do not address equity. These observations suggest a theme of providing equal opportunities to stakeholders, yet the rationales in any given setting reflect the local theories of change and other local dynamics. Within Brazil, for example, some REDD+ governance structures are characterized by a rights focus and pro-poor rationales, as within the Bolsa Floresta Program and REDD+ initiatives as Sustainable Settlements in Amazon project (Luttrell, Loft et al. 2013, Simonet, Subervie et al. 2018). Yet the Amazon Fund and expected support from the Green Climate Fund may differ.

Concerning geographies, a different focus within the literature informs the allocation of financial resources by suggesting priority areas meriting special attention. Wolosin, Breitfeller et al. (2016) show the spatial distribution of REDD+ finance can be explained to a large extent by priorities on tree cover, tree-cover loss and carbon emissions at national (70-94%) and subnational (58-72%) levels, though institutional capacity and political commitments have also been influential. Other work highlights significant gaps for specific priority areas. Some scholars point to areas in the Amazon region facing high deforestation pressure that are important for emissions and biodiversity (Nori, Lescano et al. 2013, Busch and Ferretti-Gallon 2017, Potapov, Hansen et al. 2017). Other scholars argue for additional investments in the network of protected areas given their importance to date in curbing deforestation and the risks from deforestation dynamics (Soares-Filho, Moutinho et al. 2010, Pfaff, Robalino et al. 2015). Still others argue that support should also consolidate pristine or intact or stable forests to ensure long-term conservation (e.g. Potapov, Hansen et al. 2017). While the majority of available literature strongly emphasizes improved protection of high-risk areas, at the least for prioritizing additional impacts in the short run, various goals play parts within comprehensive approaches to forest conservation.

Disbursements of financial resources in the Amazon Fund and Green Climate Fund occur on the basis of bottom-up submissions and subsequent assessments of project proposals under criteria and guidelines that are created for these funds, rather than, for example, strategic targeting of priority areas for attaining critical and agreed REDD+ objectives (Voigt and Ferreira 2015, BNDES 2017). Such analyses are also lacking from more general studies on aid effectiveness, which build on the principal-agent model and could therefore miss important details of intermediate relations (Paul 2015). This suggests that further scrutinizing how resources have been disbursed across activities, stakeholders and geographies could be useful for understanding the rationales implied in processes of financial resource allocation.

3. The Flow of Amazon Funds

Figure 1 summarizes where funding has gone. Voluntary donors, often states represented by agencies like the NORAD (Norwegian Agency for Development Cooperation), and with diverse motivations, provide financial aid to REDD+ initiatives that are inherently focused upon developing countries.

Thus, these aids are redistributed by financial intermediary organizations as the Green Climate Fund, managed by United Nations, or as the Amazon Fund, that is effectively an arm of the Brazilian Development Bank (BNDES). These organizations have a financial implementer role, approving or rejecting submitted projects according to technical requirements, criteria and its orientation.

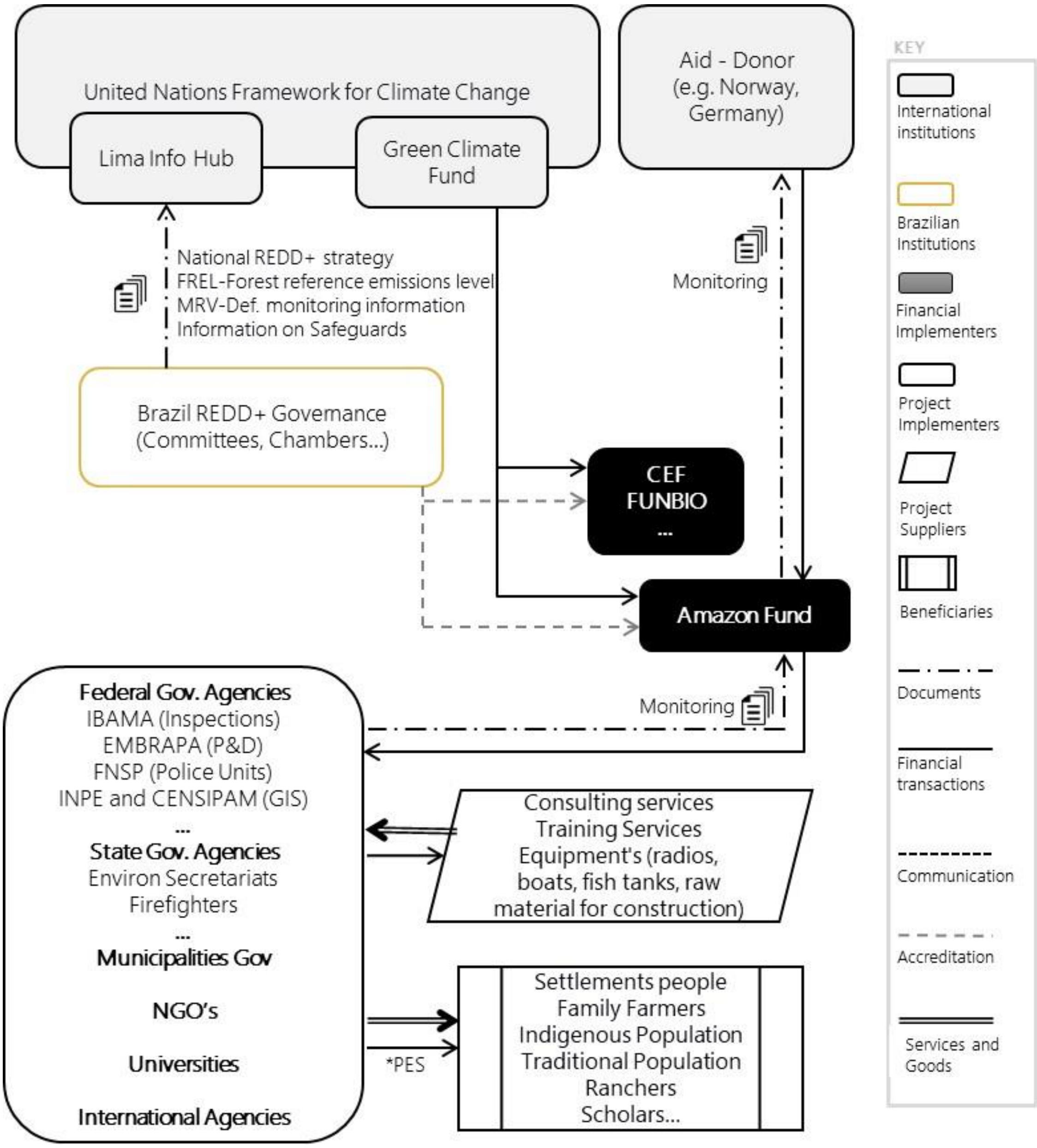

Figure 1. The Flows of Amazon Fund

For Instance, the Amazon Fund thereby makes regular financial disbursements as projects unfold, while the implementer is responsible for those expenditures generating value, in particular as defined by the donors' objectives.

The project type supported by Amazon Fund varies greatly with the category of the implementer. Activities must be categorized inside of 4 main-components, in line with the core categories for the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm): (1) monitoring and control; (2) land tenure regularization; (3) sustainable production activities; or (4) scientific and technological development. Government agencies, for instance, ask for support to improve, implement or maintain operations, acquire technologies and images, train employees, and rent or buy equipment. The value generated includes deforestation monitoring, inspections and overall the capacity to implement environmental policies - though whether support merely substitutes for other funding is one key question. Other supported activities directly reach beneficiaries, for instance sustainable production pilot projects, equipment donations to raise participation in supply chains, payments within PES programs and moreover. This paper aims to look back and assess the accomplishments and shortfalls in order to draw lessons for REDD+ and RBA in Brazil and other tropical countries, examining the geographical, thematic and institutional distribution of the resources from the AF. For organizing the information on disbursements, a key choice is the geographic unit that is to be used. In Brazil, the smaller geographic unit for monitoring deforestation, applying public policies, allocating government resources and evaluating outcomes is the municipality. Assigning disbursements from the Amazon Fund by municipality is challenging because some project activities are not directly related to specific locations. Others have specific spatial targets such as biomes, river basins, protected areas or indigenous territories.

We determined the municipalities covered by each project. Disbursements across multiple municipalities are allocated, within our database, using the sizes of municipalities (depending the project aiming, the indigenous territories and protected areas can be or not to be discounted). They are also allocated across their main-components, using the PPCDAm core categories. Our database also includes field data from different sources not available at project level. The procedures for collecting and interpreting data, and constructing the database, are in the supplements.

Certainly, our core source is the Amazon Fund web site. We collected all of the data available on all of the 96 projects through the end of 2017, for instance: initial date; estimated completion date, objectives; beneficiaries; implementer; territorial scope; amounts from the Amazon Fund; disbursements; fulfillment of commitments; and activities conducted. Project web sites maintained by implementers also provided information. As a project can have multiple main-components, interviews were conducted (by email) and then a spreadsheet was filled out by an Amazon Fund manager to indicate the share of each main-component within the total amounts for each project.

Reliable information about projects at the municipal level is the heart of this research. After determining a complete list of municipalities affected at all, we also wanted to reasonably divide a project's disbursements across all of those municipalities (see Diagram 1 and Table 2 in the supplements for the rules and additional information utilized), as noted above, and within each of them across main components (see Diagram 2 and Table 3 in the supplements for these rules and additional information utilized). Finally, we broke down those component disbursements by activities (also called specific-components). If more than one activity by main-component was verified, then a main-component disbursement was prorated across them. After all of this division, the final database (see in the supplements) has 10,493 lines of information structured as project, municipality, main-component and activity.

All disbursements to the Amazon Fund are converted from US dollars to Brazilian reais using the rate for the day they are received, then all disbursements from the Amazon Fund are accounted (as per above) in units of reais. For reports and publications in English, the Amazon Fund converted amounts using the rate for the day each respective project was approved, thus we use this convention and present units of dollars. For Brazilian governmental agencies (accountable in reais), we used an average exchange rate for 2009-17 when looking at historical trends in quantities, in order to reduce the effects of exchange rate fluctuation.

4. Results: resource allocations by the Amazon Fund

In the early 2000s, Brazilian forest governance improved in terms of law enforcement and the introduction of new policies and institutions for forest conservation, which resulted in plummeting deforestation rates (Cunha, Börner et al. 2016). At the same time, Brazil fiercely resisted international schemes involving future obligations to reduce deforestation, most notably in the form of carbon offsets (Carvalho 2012). In Norway, a window of opportunity opened for substantial investments in deforestation reductions abroad in the form of official development Aid (ODA). This combined neatly with Brazil's desire to be compensated for carbon-emissions reductions it was producing (Hermansen 2015). In August 2008, the Brazilian government legally established the Amazon Fund (law 6.527/2008) to receive compensation for past achievements, albeit with the expressed objective that resources would support activities to further reduce deforestation (Van der Hoff, Rajão et al. 2018). Soon after, other donor organizations including the German government and Petrobras followed suit. By the end of 2017, the Amazon Fund had received USD 1.2 billion, mostly from the Norwegian and German governments. After 10 years, the Amazon Fund is the largest REDD+ related results-base instrument in the world (Wolosin, Breitfeller et al. 2016), having committed USD 667.3 million (i.e., a little over half of the donations received) to support the 96 projects approved by that point (BNDES 2017).

Currently, disbursements are made on the basis of criteria and guidelines updated biannually by the Fund's steering committee (COFA). The 2017-2018 document lists 14 minimum requirements that potential projects must meet, some (i.e. items B4, B5, B6, B7 and B14) determining conceptual boundaries of project activities. Projects must be in at least one of the thematic areas outlined in law 6.527/2008, namely: (1) public forest management; (2) monitoring, control and enforcement; (3) sustainable forest management; (4) sustainable economic activities; (5) ecological-economic zoning; (6) conservation and sustainable use of biodiversity; and (7) regeneration of deforested areas. They also must demonstrate coherence with environmental and forest policies, most notably the national Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), including its manifestations in state governments (PPCDs), and the national policy for Regenerating Native Vegetation (ProVeg). These plans establish three core categories that also constitute a basis for project assessment, namely: (A) monitoring and control; (B) land tenure regulation; and (C) sustainable production activities (BNDES 2017). Projects are also evaluated with respect to coherence with Brazil's National REDD+ Strategy (ENREDD+), which in turn incorporates implementation of PPCDAm and compliance with the Brazilian Forest Code. Finally, projects are expected to be financially additional, i.e., go beyond existing public environmental budgets and other forms of finance. Given these rules, any organization may submit a project proposal to BNDES for financial resources.

4.1 - Distribution Across Space

Spatially, Amazon Fund allocations display some concentration (Fig.2a) in 68 municipalities along the 'Arc of Deforestation', a region where the agricultural frontier advances towards the forest and also where are the highest rates of deforestation of the Amazon that goes from the east and south of Pará towards the west, passing through Mato Grosso, Rondônia and Acre. This concentration is due to the projects from the NGOS (Fig. 2d), since the federal and state projects had no significant contribution mainly because these projects tend to focus on benefits of which are statewide or nationwide (Fig. 2b and 2c). State government projects are mostly responsible (Fig. 2b) for monitoring and control, specialty in activities as structuring of Environmental Secretariats, CAR implementation, and Firefighters (activities detailed in section 4.2). The states that more actively sought the support of Amazon Fund for monitoring and control were Acre, Maranhão, Tocantins and Rondônia. Acre state, beyond its projects in monitoring and control, has a strong presence in investments in sustainable production spread throughout its territory.

Federal government projects are the most evenly distributed across the landscape, averaging below 26 USD/ha, which could be due to the all-encompassing nature of GIS and remote sensing. At the same time, federal investments more likely to feature large agencies have, higher concentrations in eight cities in the Legal Amazon, including Rio Branco, Manaus, Boa Vista and Macapá, all of which host the Brazilian Agricultural Research Corporation (EMBRAPA) units (Fig. 2c). Finally, while municipalities benefit indirectly from various types of support, direct support only went to 6 of the 772 municipalities in the Legal Amazon and was accumulated to only USD 7.8 million. Most of that (65.2%) went to the municipal government of Alta Floresta, in northern Mato Grosso. In addition, the Amazon Fund had also financed research of the State Universities of Pará (in Belem) and Amazonas (in Manaus) as well as GIS and satellite training by INPE – the Brazilian Institute for Space Research (in Manaus).

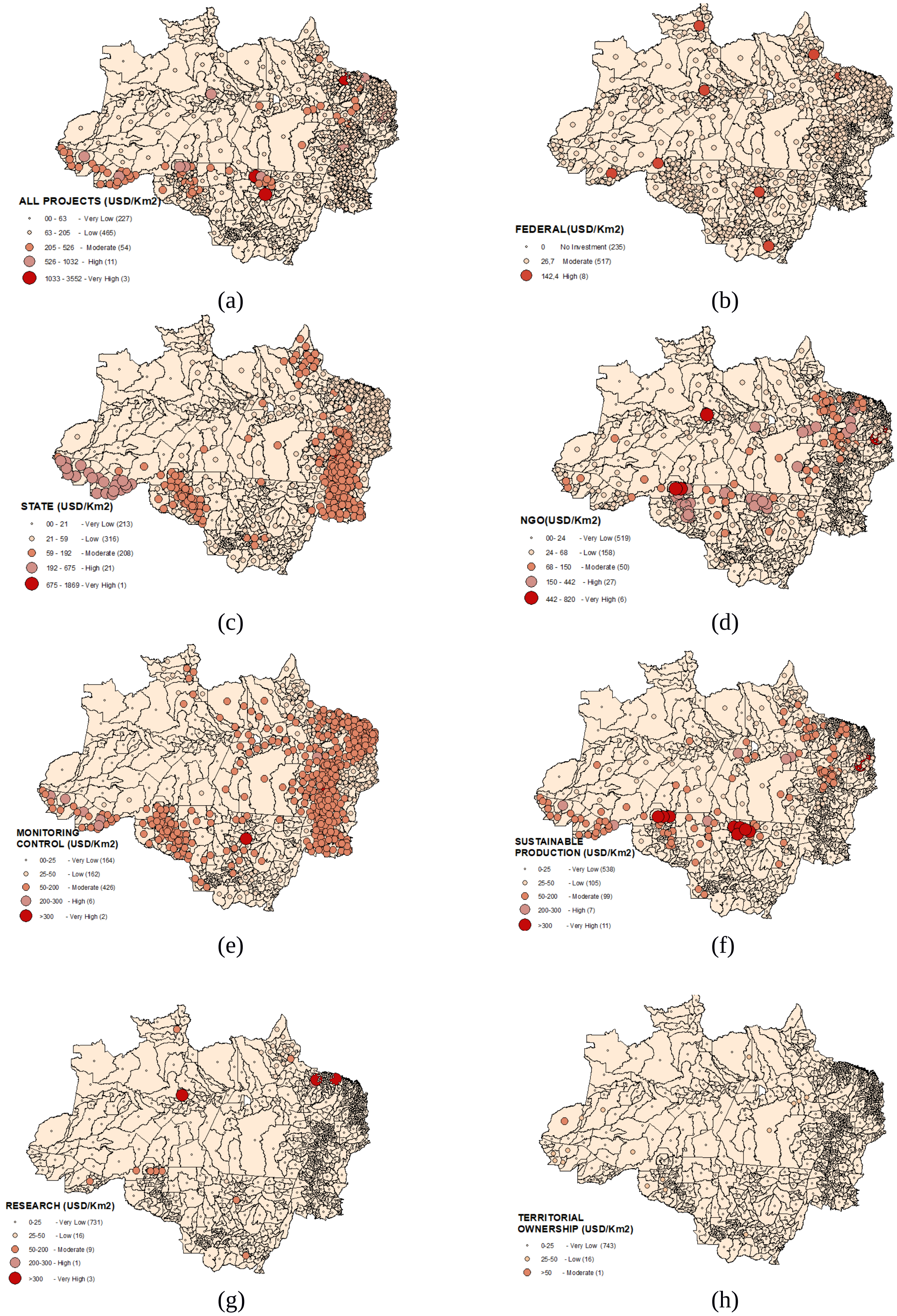

Figure 2. Spatial distribution of AF investments per municipality by Stakeholder and main-component

4.2. Distribuition Across Activities

4.2.1. Commitments & Disbursements

The Amazon Fund has focused on its main-components, composed by the three strategic investment categories of PPCDAm − again (1) land tenure regularization, (2) monitoring and control, (3) development of sustainable production activities – while adding a fourth category, scientific and technological development. Almost half of the commitments (USD 326.7 of the 667.3 million) has gone to monitoring and control (USD 326.7 million) while one third (USD 201.9 million) went to sustainable production (see figure 3 and table 1). The latter category has been relatively steady over time, as have the small land tenure commitments, but the large flows to monitoring and control have been uneven over time: starting slow with an average of USD 20.3 million in the first four years; peaking in 2013 at USD 94.0 million, followed by USD 59.9 million in 2014; and then settling at an average of USD 30.6 million from 2015 on (Fig.3 left panel). Finally, nearly all commitments for scientific and technological development occurred in 2012 (USD 40.7 million).

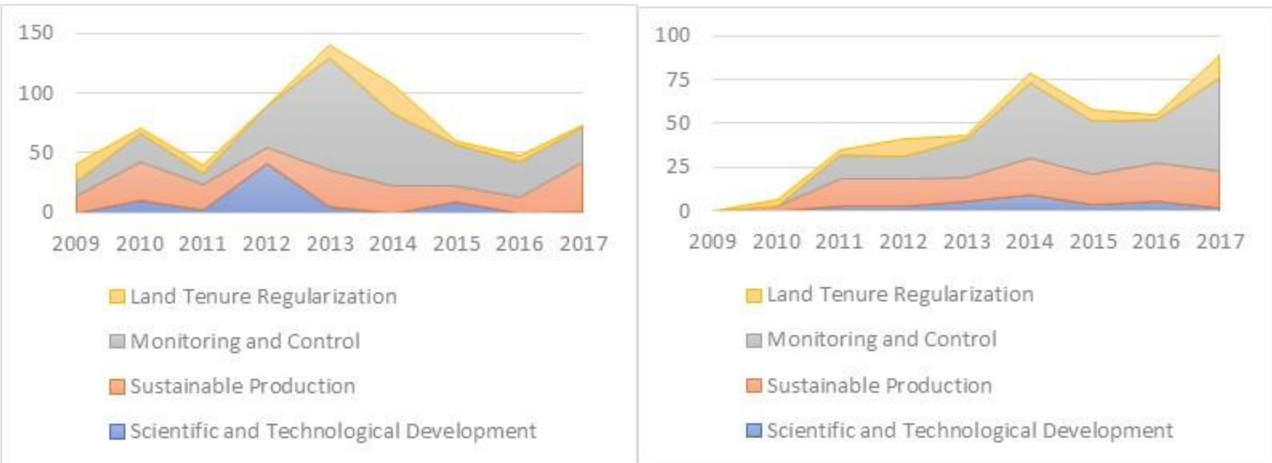

Figure 3. Annual committed (L) and disbursed (R) amounts per main-component (in million USD)

Actual disbursements to individual projects, while slower than noted above, have reflected the commitments, with most disbursements going to monitoring and control (49.6%) and sustainable production (31.9%). Monitoring and control was responsible for most of the variation (see right graph of figure 3), peaking in 2014 (USD 43.1 million) and 2017 (USD 53.5 million). Disbursements for scientific and technological development have notably never really gotten much traction, never being very high and falling after the peak in 2013 and 2014.

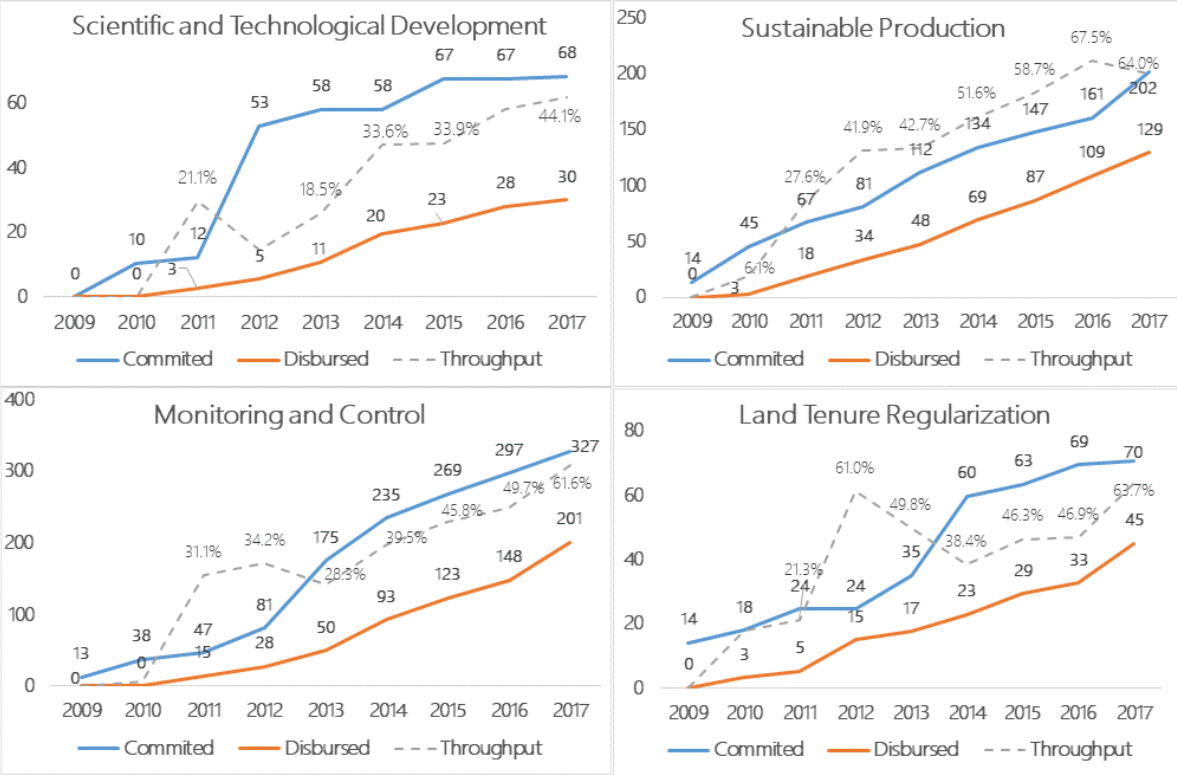

Figure 4. Temporal execution rates of consolidated disbursements as % of consolidated committed amounts by main-component

4.2.2. Specific Activities

Monitoring and control efforts involved mostly state (USD 187.1 million) and federal government (USD 100.1 million) projects. It was the only category, though, that included the unique international project supported by the AF aiming help develop the capacity to monitor deforestation in 8 neighbors' countries also covered by the Amazon Biome (USD 11.8 million). Yet most of the monitoring and control investments (USD 113,0 million) were for implementation of CAR. A large share of the funds provided for such activity (USD 102.5 million) were allocated to state government to acquire equipment (GPS, computers, software) and training for effective processing of proposals to CAR. Also, USD 52 million was for environmental secretariats to build capacity to implement CAR as well as other environmental policies. Those efforts included the creation of municipal secretariats, the acquisition of cars as well as buildings, the hiring of employees and training in monitoring deforestation, landscape analysis, sustainable supply chains and measurement. In addition, some resources were used to promote the CAR among landowners and to provide georeferencing services for landowners. A small set of resources went to development of a state system for granting environmental licensing to new businesses and companies.

Other monitoring activities that were exclusively federal involved the improvement of GIS and satellite imaging systems for fighting against deforestation (PRODES and DETER, USD 76.1 million) and forest fires (PREVFOGO, USD 6.3 million). State governments also invested in fighting against forest fires (USD 32.5 million) but to create units of firefighters rather than to monitor. Other federal government investments included the strengthening of law enforcement (USD 29.6 million) in two projects (IBAMA - Brazilian Institute for the Environment and Renewable Natural Resources and FNSP National Force Police), mostly for vehicles, helicopters, equipment and buildings. While NGOs received a lot from the Amazon Fund (USD 241.1 million), monitoring and control only received USD 11.6 million that was spent on supporting CAR.

In the category of sustainable production, by contrast, resources mostly went to NGOs (USD 154.7 million) and state government organizations (USD 42.1 million) (see table 1). Nearly all state governments investments went to the promotion of sustainable forest activities, acquisition of equipment (tanks, driers, processing units' machines, warehouses) and the provision of professional training and technical assistance (in pisciculture and aquaculture, nut and açaí extraction, pasture management, as well as forestry and agroforestry systems).

Investments in regularizing land tenure almost exclusively came from state governments (USD 23.8 million) and NGOs (USD 46.6 million), notably spending on territorial zoning and protected-area management and indigenous lands. This provides indirect benefits for indigenous peoples, quilombos (descendants fugitive slaves), riverine people, smallholders and settlements. No such investments were federal. Federal governments did invest substantially in scientific and technological development, which involved field data collection by the Brazilian Forest Service (SFB) for building the National Forest Inventory (USD 31.7 million).

Universities, by contrast, invested most financial resources in scientific publications (USD 4.7 million) and development of the research infrastructure (USD 3.9 million). One project from the Federal University of Pará conducted research for the development of new products from bioactive compounds of plants typical of the Amazon Biome (USD 0.7 million), an investment in the development of new forest products such as herbal medicines, cosmetics and food products, among others. Natura, a private cosmetics company from Brazil, announced in 2016 an investment of more than USD 70 million in biodiversity inputs as part of its Amazon Program that aims to develop a new line of products with origins in Amazon Biodiversity.

Table 1**.** Distribution of project approvals to Amazon Fund projects (USD)

ACTIVITIES	Stat. Gov.	Fed. Gov.	Mun.Gov	Int.	NGOs	Univ.	TOTAL
Scientific and Technological Development	**4.457.301**	**40.461.961**			**13.990.780**	**9.383.341**	**68.293.383**
Field collection and data inventory (Forest, Socioeconomic, Biodiversity, Maps)	1.771.039	31.709.135			366.095		33.846.268
Disseminate Environmental Education (Museum)					5.818.209		5.818.209
Development of New Forest Products						732.695	732.695
Develop environmental diagnoses and shared management tools, edit bulletins and publications					1.693.133	4.736.591	6.429.724
Investment in research infrastructure (Laboratories, equipment, facilities, universities)	1.771.039				1.263.966	3.914.055	6.949.059
Research on the production of native seedlings and techniques for reforestation of degraded areas, development of Demonstration Units (pilots) to disseminate knowledge	915.224	8.752.827			4.849.377		14.517.427
Sustainable Production Activities	**41.186.376**		**5.984.174**		**154.736.705**		**201.907.255**
Economic Activities for Sustainable Forest Use and Recovery of Degraded Areas	41.186.376		5.984.174		154.736.705		201.907.255
Monitoring and Control	**187.105.638**	**100.146.294**	**1.788.272**	**11.791.988**	**25.845.426**		**326.677.619**
Structuring and strengthening of State and Municipal Environment Secretariats (Acquire infrastructure, training in Monitoring deforestation, Landscape Analysis, Sustainable Chain and Recovery Measure techniques)	52.018.486		1.376.210		14.254.668		58.656.955
Inspections, Enforcement and Environmental Police		29.571.660					29.571.660
Combat Forest Fires (States – Firefighters / Federal – GIS and Satellites)	32.543.336	6.282.451					38.825.788
Regularize the environmental situation or/and implement CAR	102.543.816		412.062		11.590.759		113.007.430
Improve Deforestation Monitoring System (GIS and Satellites) **		64.292.183		11.791.988			76.084.171
Land tenure regularization	23.829.953		62.995		46.552.443		70.445.392
Land Regularization of Small and Middle size properties (Tenure, Deeds)	1.141.031				3.219.703		4.360.735
Territorial and Ecological Zoning, strengthening and empowerment of PAandIT Management	22.688.922		62.995		43.332.740		66.084.657
Total	256.579.269	140.608.255	7.835.441	11.791.988	241.125.355	9.383.341	667.323.649

4.3. Distribuition across Stakeholders

4.3.1. Commitments & Disbursements

The distribution of commitments across stakeholders shows some variation across years (Fig.5 left panel). In 2017, over 95% of a total of USD 667.3 million went to state governments (USD 256.6 million) or NGOs (USD 241.1 million) or federal governments (USD 140.6 million), with their shares varying considerably per year. Of a total of USD 140.4 million in 2013, about 70% (or USD 102.9 million) went to projects of state governments that received almost no such commitments either two years earlier or two years later. By contrast, commitments to NGOs projects were relatively stable over time, averaging USD 22 million until 2016, though rising to USD 44.5 million in 2017 (implying variation in NGOs' share). Commitments to federal government projects were also uneven, with slight peaks in 2012 and 2017 (USD 31.7 million, 41.2 million).

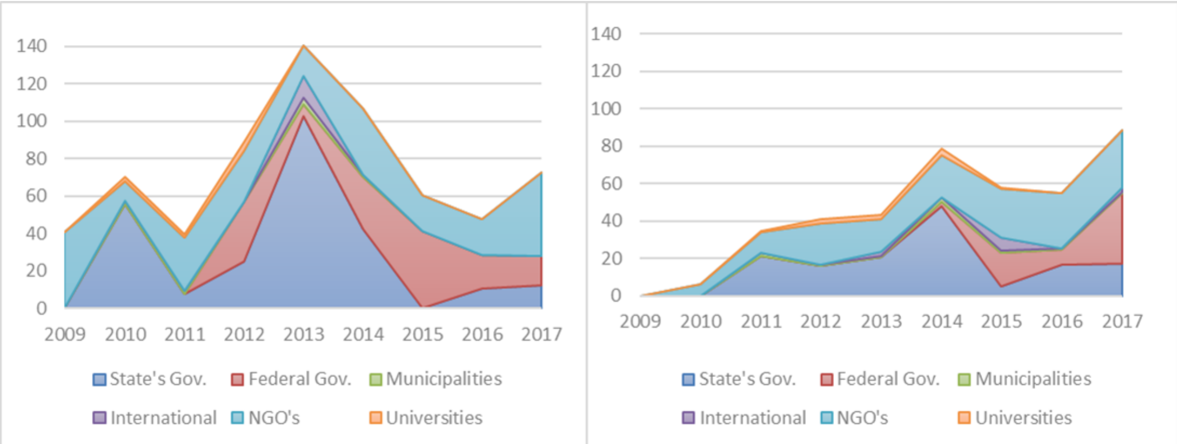

Figure 5**.** Annual committed (L) and disbursed (R) amounts per stakeholder (in million USD)

Disbursement have lagged those commitments (Fig 3. right panel). Only USD 405.3 (i.e. 60.7 %) of 667.3 million has been transferred to project owners. Average annual disbursements to state governments have hovered between USD 16 and 21 million in most years, with a sudden peak of USD 47.6 million in 2014 and then a sharp drop to USD 4.8 million in 2015. Disbursements to federal government increased exponentially from a small base of only USD 2.4 million even by 2014 to USD 37.7 million in 2017. Finally, disbursements to NGOs steadily increased from USD 6.4 million in 2010 to USD 30.7 million in 2017.

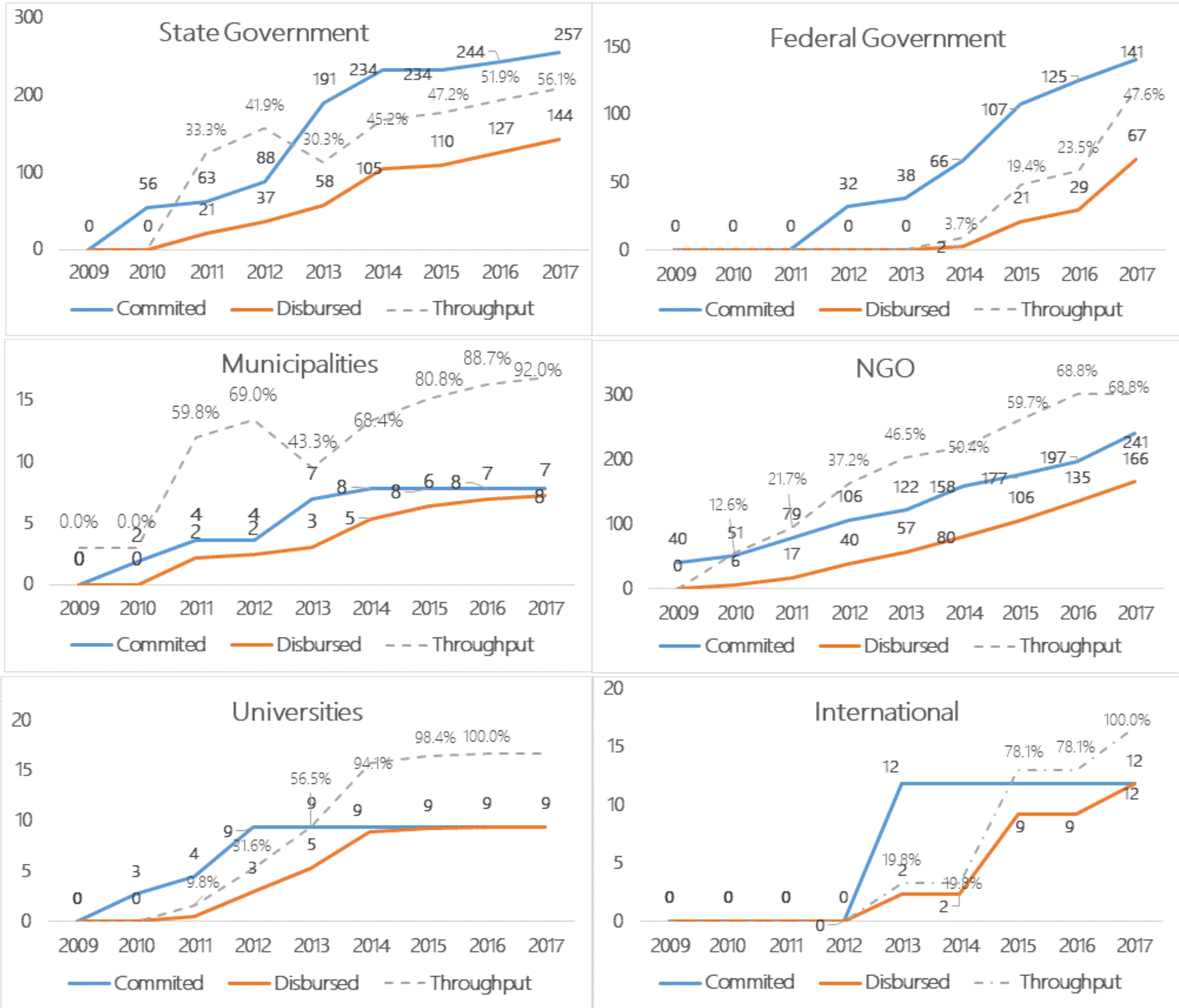

Figure 6. Temporal execution rates of consolidated disbursements as % of consolidated committed amounts by Stakeholder

4.3.2. Project Details

To understand these variations in disbursements, we must consider further details. Federal government projects, for instance, were concentrated within eight projects involving six recipient agencies. Of the total amounts in this category, USD 64.3 million (i.e. 47.2%) went to organizations that develop GIS and provide information on deforestation trends, namely INPE and CENSIPAM (Management and Operations Center for the Amazon Protection System linked to the Ministry of Defense). Another USD 35.9 million (i.e. 26.7%) went to organizations responsible for enforcing environmental laws and policies, namely IBAMA and FNSP. The remaining USD 40.5 million (i.e. 25.9%) went to EMBRAPA units to disseminate knowledge about sustainable production and recovery of degraded areas throughout Brazil, and to the SFB to the collection of information aiming increase the forest data available (see section 4.2).

One potentially critical observation is that these disbursements to federal government agencies coincided with decreased budgets for them, in particular after 2014 (Fig.5), suggesting a partial substitution for agency expenditure of taxpayer-funded budgets using the Amazon Fund. For instance, IBAMA's executed budgets to reduce deforestation, combat fires and conduct environmental inspections were reduced from USD 50.64 million in 2014 to USD 29.07 million in 2017, a shift occurring in parallel with rising disbursements from the Amazon Fund disbursement. Similarly, INPE´s budget fell from USD 84.5 million in 2010 to USD 43.63 million in 2017, alongside increasing disbursements from the Amazon Fund (USD 27.51 million) between 2015 and 2017, and CENSIPAM has similar trends. Those trends include rising execution rates for turning federal commitments into disbursements, which increased from 3.7% in 2014 to 26.8% in 2017.

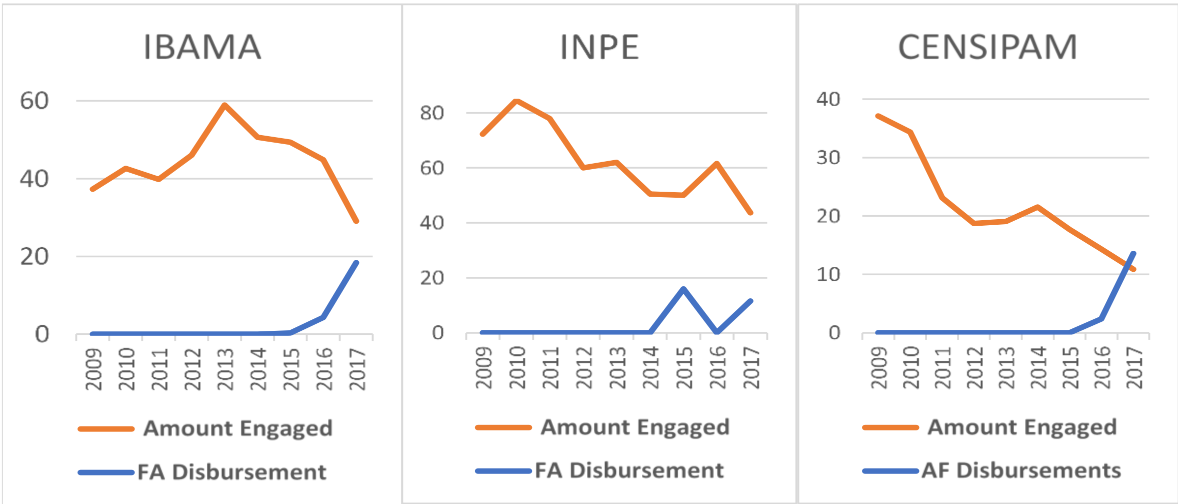

Figure 7. Comparison of Federal Engaged Budgets with the Amazon Fund disbursements for INPE, IBAMA and CENSIPAM (for this figure used average 2009-2017 exchange rate: 2.434)

These observations, despite not be an impact evaluation enabling prove a direct causal relationship between the raise of disbursements with the reduction of budget from federal agencies on deforestations actions (e.g. maybe the federal government has less resources and reduced a budget in all fronts), at least suggest a lack of additionality, match the contextual factors such as an unfavorable political climate for environmental protection (Aamodt 2018), more flexibility within forest legislation since 2012 (Sauer and França 2012), multiple bills for reducing environmental protection during election year 2018 and, as a consequence of all these factors, rising deforestation rates since 2014 (Rochedo, Soares-Filho et al. 2018).

The committed and disbursed peaks for state government projects in 2013 and 2014 (Fig.5) corresponds with contextual factors as well, including a surge in state government projects toward development and implementation of the Rural Environmental Register (CAR). CAR is a federal policy instrument introduced in 2012 with the adoption of the new Forest Code (law 12.651/2012) to enhance law enforcement capacity. Yet despite the federal law and a centralized national system (by SFB), the registers must be executed at state or municipal level (art 29, §1). Thus, since the CAR's formal establishment in 2012, implementation has become a major concern for state governments, especially after the system went live in 2014 (Azevedo, Rajão et al. 2014). This can be seen in both spending and appeals to the Amazon Fund (BNDES 2018). Within the 13 states that have approved projects, 85% of disbursements went to seven of the nine inside the Amazon Biome.

Finally, the linear increase in disbursements to NGOs reflects yet another set of contextual factors, in this case related to Amazon Fund process adjustments over time. Disbursements to projects were slow, to start, due to rigid assessment procedures intended to show professionalism, in the eyes of donor organizations and BNDES management, that also reflected some lack of understanding of project owners (BNDES 2018, Van der Hoff, Rajão et al. 2018). Minutes of the COFA meetings indicate that, in response to these challenges, the Amazon Fund adopted a number of measures in order to facilitate and accelerate the disbursement process, including public calls for submitting project proposals. While the consequences of these responses are reflected in the linear increase in approved projects and disbursements to NGOs, the financial resources were not evenly distributed. We find that 80% of the disbursed amount was distributed among half of the NGOs high-capacity and professional organizations, such as the Sustainable Amazon Foundation (FAS), the Amazon Institute for Human and Environment (IMAZON), and The Nature Conservancy (TNC)

5. Deducing the accomplishments and shortfalls of the Amazon Fund

This paper looked back and assessed the accomplishments and shortfalls of AF aiming to draw lessons for REDD+ and RBA, examining the geographical, thematic and institutional distribution of the resources from the AF and exposing the underlying rationales adopted for redistributing financial resources, which is useful for identifying the main factors for successful or failing forest conservation aid.

Our findings on the distribution of financial resources across stakeholders, firstly, reveals great variation in adherence to the categories outlined by Luttrell, Loft et al. (2013). Federal government organizations primarily supported the development of monitoring systems

(45.7%) and inventory data (22.6%), which denotes a main concern with gaining control over deforestation dynamics. State government organizations have invested mostly in the implementation of various REDD+ components, including CAR (40.1%) and sustainable production activities (16.1%), thereby suggesting an emphasis on effective facilitators of REDD+ implementation. In addition, they have supported capacity development for state and municipal organizations in various ways (20.3%) and have substantially contributed to the consolidation of land tenure for various socioeconomic groups (9.3%). While this latter may appear to benefit cost-incurring groups, forest stewards or poor communities, it rather reflects a direct investment in strengthening their legal rights to land. Investments by NGOs have mainly benefited local communities that aim to adopt sustainable production activities (64.2%), but have also supported (more than federal or state government organizations) land tenure regularization projects (19.3%). These observations suggest that benefit distribution in Brazil is quite diverse and each stakeholder seems to adhere to a different logic (Luttrell, Loft et al. 2013). We found no evidence, however, that recipients of financial resources from the Amazon Fund have directly targeted high emitting or carbon preserving groups, which is surprising considering that the Amazon Fund has explicitly stated emissions reductions as its main objective.

Our findings on the distribution of financial resources across activities, secondly, indicate that the Amazon Fund's financial resources were channeled towards the direct and structural drivers of deforestation, but this was not proportional to the importance of addressing these drivers as argued by some scholars (e.g. Weatherley-Singh and Gupta 2015). For instance, investments in combatting forest fires and illegal logging amounted to only 10.2% of total disbursements, whereas 10.6% of total resources supported land tenure regularization. By contrast, most resources were invested in sustainable production activities (30.3%), CAR implementation (17.2%), scientific and technological development (10.2%) and capacity building (10.1%). As a consequence, our findings correspond with arguments by Weatherley-Singh and Gupta (2015) in that no financial resources were channeled towards mitigating the impacts of cattle ranching, road construction, international demand for agricultural products or corruption. Although we confirm that financial disbursements by the Amazon Fund are conditional upon meeting the requirements for reinvestment in deforestation reduction (Van der Hoff, Rajão et al. 2018), we found no evidence that these disbursements were intentionally channeled according to the contribution of these activities to deforestation reductions. As financial resources were distributed upon demand, albeit with project quality requirements, each stakeholder category seems to have adopted a different investment strategy. For instance, federal and state government organizations emphasized monitoring and control activities, whereas NGOs mostly invested in sustainable production activities. In this respect, we find that the recipient organizations, rather than the Amazon Fund, determine the investment strategy, at least in this category of analysis.

The third component of our analysis, namely the spatial distribution of financial resources, has given quite different insights into the effects of the Amazon Fund. As already observed in section 4.1, we have observed that disbursements from the Amazon Fund to the three main recipient categories have generally benefited municipalities located in areas where deforestation threats are highest (Lovejoy and Nobre 2018). This observation only partially corresponds with findings by Wolosin, Breitfeller et al. (2016) as we found no evidence of substantial contributions to areas with high tree cover, which are more commonly found in remote areas of the Amazon biome (Potapov, Hansen et al. 2017). Moreover, federal and state government projects have had no significant contribution to the concentration of benefits along the deforestation arc, mainly because these projects tend to focus on scientific and technological development as well as monitoring and control activities, the benefits of which are statewide or nationwide. The NGOs projects for territorial and ecological zoning, strengthening of PA and IT management as well sustainable production represent 30% of total disbursements from the Amazon Fund, many of them applied in the arc of deforestation.

The analysis of spatial observations strengthens the position that the Amazon Fund's financial resources not were channeled towards the direct and structural drivers of deforestation proportionally to the importance of these drivers, as argued by some scholars. One may argue that investments by the former support more structural improvement for nation-wide instruments like CAR, but it is still unclear whether and to which extent such instruments indeed contribute to reducing deforestation, since scholars are arguing that CAR effect has not been systematic across time and space indicating that the policy is only partially effective (Azevedo, Rajão et al. 2014, Costa, Rajão et al. 2018).

Our findings indicate that the Amazon Fund supports a myriad of different stakeholders, activities and regions without a coherent strategy for the distribution of financial resources. While most financial resources were channeled to the strengthening of monitoring and control activities by federal and state governments (USD 287.2 million), their investments have focused on monitoring activities like satellite imaging (USD 70.6 million) and CAR implementation (USD 102.5 million). By contrast, investments in control activities like combat forest fires

(USD 32.5 million) or law enforcement (USD 29.6 million) were substantially smaller. Furthermore, state government investments in monitoring and control activities were generally concentrated along the deforestation arc, but there is a clear gap in northern Mato Grosso where investments have been much lower (see fig. 2). Finally, our results in section 4.3.2 also reveal a negative relation between disbursements to federal government organizations and their budgets for environmental protection, suggesting that the financial resources from the Amazon Fund have not prompted additional gains. Despite this not represent a causal relationship, is recommend to AF consider safeguards and criteria's to further cash disbursements to ongoing projects These inconsistencies may have jeopardized the attainment deforestation reductions, which could partially explain why deforestation rates have been rising since 2013 despite increased disbursements from the Amazon Fund (Van der Hoff, Rajão et al. 2018). This does not imply that the Amazon Fund should abandon disbursements to governmental organizations and switch to alternative activities and stakeholders. The substantial investments in sustainable development activities by NGOs (USD 154.7 million), for example, are indeed important for stimulate economic activities that do not require deforestation, but these projects require much closer scrutiny in order to understand the extent to which they indeed reduce deforestation. Instead, we argue for a redistribution of disbursements to governmental organizations in a way that resolves the aforementioned inconsistencies. Examples could be to increase emphasis on control activities, emphasize projects in northern Mato Grosso and/or avoid substitution of governmental budgets by improving transparency on spending.

6. Conclusions

This research paper has made a sincere effort to understand the underlying rationales for the distribution of financial resources from the Amazon Fund in absence of a strategic approach. In doing so, we have identified which stakeholders, activities and geographies are being targeted and where the financing gaps may have occurred.

As a general lesson learned for REDD+ and RBA, this article concludes by pointing to the need to develop a science-based strategy for investing the increasingly scarce resources of the AF in order to secure stronger results on the long term, making the distribution of financial resources in a more strategic manner. This is especially important as the political climate in Brazil and in the Word has become more hostile to environmental interests (Fearnside 2016, Lovejoy and Nobre 2018, Rochedo, Soares-Filho et al. 2018). The Amazon Fund could play an important role in ensuring that financial resources are channeled to activities, stakeholders and regions where impacts may be greatest and where contributions add to already existing efforts and obligations.

Our analysis also helps to understand why empirical studies seem ambiguous about the effectiveness of forest conservation aid. As explained in section 3, BNDES' approach to distributing financial resources from the Amazon Fund to individual projects occurs based on the evaluation of project proposals from diverse organizations rather than a strategic selection of projects based on a predetermined theory of change. As a consequence, our findings show that disbursements by the Amazon Fund to individual projects reflect an arbitrary support of different projects that adhere to very diverging theories of change within a broader REDD+ and RBA strategy. Although this refutes any suggestion that BNDES pursues other interests than deforestation reduction, this arbitrariness of disbursements suggests that the Amazon Fund is not primarily concerned with attaining further deforestation reductions, but rather supports the broader policies that are or should be. The financial transactions to Amazon Fund, as an intermediary organization, are conditional on demonstrated achievements in reducing emissions from deforestation, whereas the conditions for redistribution require adherence to national policies. Although the Amazon Fund contributes to attaining REDD+ objectives to some extent, as an intermediary organization it is not responsible for this attainment and may therefore foment political controversy (Van der Hoff, Rajão et al. 2018). Similar processes may underlie some of the aid effectiveness studies (Bare, Kauffman et al. 2015, Hermanrud and de Soysa 2017, Restivo, Shandra et al. 2018), but empirical analysis will be necessary to verify this hypothesis.

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Supplements

Database Modeling and Structuration

The Figure 8 depicts the model proposed by this research for the database structuration, where the levels are represented by arrows and the main variables clustered by these levels. The variables were collected from 5 different origins: (1) Amazon Fund official reports and website; (2) Field research at BNDES - Amazon Fund; (3) Spatial data collected in the websites from federal agencies as IBGE, FUNAI, MMA, IBAMA and INPE; (4) Mathematical propositions using decision rules build based at literature review; (5) Author assumptions. These variables are clustered by level as described below:

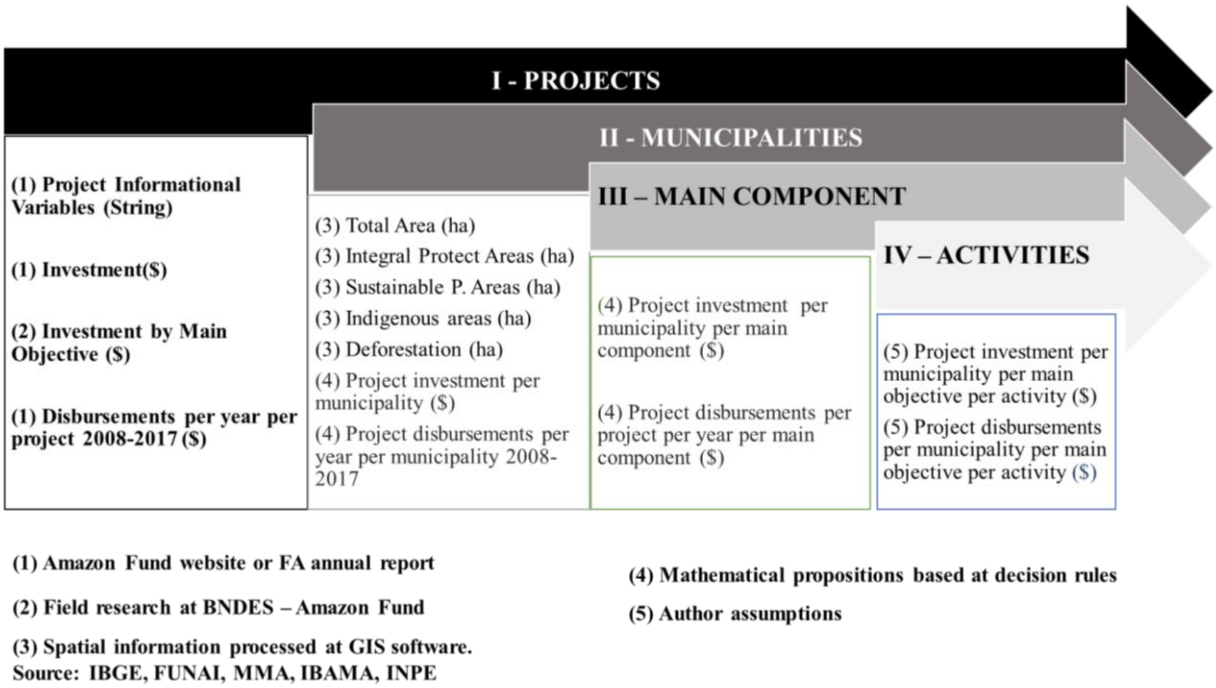

Figure 8 Model for Database Structuration

I - PROJECTS: Variables with data at project level. The Amazon Fund presents its investments, objectives, scope and results always in projects.

II - MUNICIPALITIES: The project data are disaggregated by the municipalities affected by them. As previously explained, the lowest level for public policy enforcement and deforestation assessments in Brazil are the municipalities. Also, at the municipal level, most of the data generated by the various Brazilian government agencies (federal, state and municipal) is made available. The municipal deforestation rates, the municipalities listed as critical by Ministry of Environment due to their high historical deforestation, municipal agricultural production census, livestock, socioeconomic indicators, among others, can be cited as examples of municipal variables relevant to this research.

III – MAIN COMPONENTS: The investments and disbursement variables for each project disaggregated at municipal level in last step, are divided by main components:

- Promotion of Sustainable Production Activities: Activities that keep the forest on its feet and have economic attractiveness;
- Monitoring and Control: Government actions that ensure the adaptation of anthropic activities to environmental legislation;
- Land Tenure Regularization: Actions of territorial organization;
- Scientific and Technological Development: Science, technology and information actions that contribute to recovery, conservation and sustainable use;

IV – ACTIVITIES: The investments and disbursement variables for each Main Component are then disaggregated for each activity.

With the model proposed, the Figure 9 shows the steps used to collect the variables.

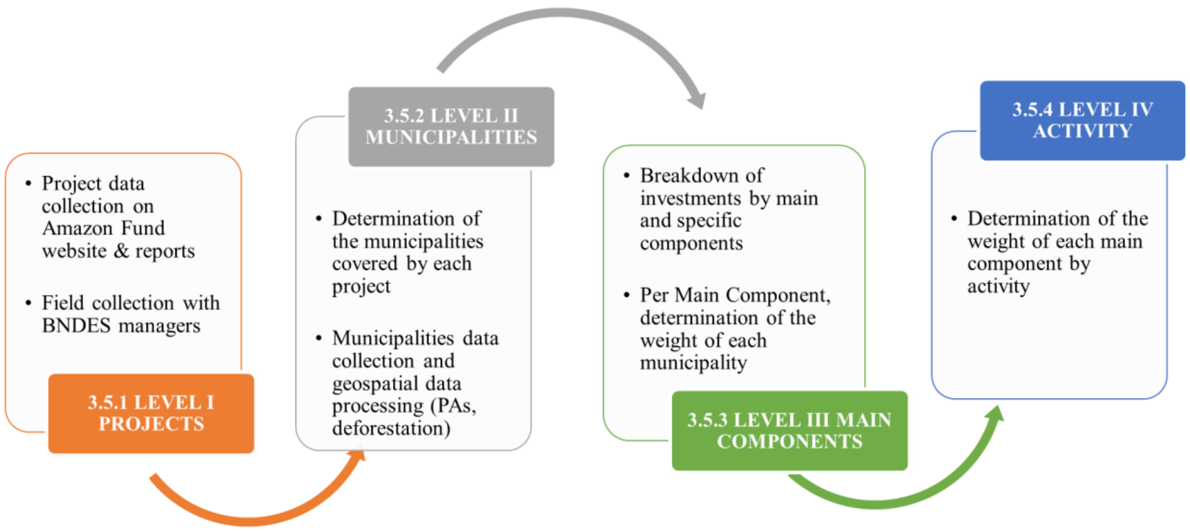

Figure 9 Steps to collect the variables

Project data collection on Amazon Fund website & reports: Aiming to make their data transparent to donors, society and the international community, the Amazon Fund makes constant updates on its website with information about the ongoing of the approved projects. The initial step described in Figure 9 is collect the project variables. Figure 12 shows the webpage from which data were collected from the 96 projects in status contracted, approved or completed from the Amazon Fund, considering the cutoff date of December 31, 2017. Projects with status as in consultation or in perspective don't have a detailed page in Amazon Fund website and not were considered at this research. This information is included as variables for each project in the database (see Figure 8), as:

- Project Management & Implementer (Stakeholder): Shows the name of the entities that receive the financial support and are responsible for the project implementation. Occasionally intermediary entities are used to sub allocate the funds to several small associations, often entities without the structure to manage a project directly with the Amazon Fund;
- Implementer category (stakeholder): Federal Government, State Government, Municipality, NGO, University or International
- Territorial Scope (string): Represents the area covered by the project. It may be a state administrative region, one or several states, biomes, hydrographic basins, protected areas, indigenous territories;
- Beneficiary (string): Population that will be directly benefited by the project, like the traditional populations that live in the area, ranchers, indigenous people
- Objective (string): describe the project objectives;
- Total Cost of the Project (numeric): The total cost of the project is presented, that is, the sum of the amounts financed by the Amazon Fund added by the counterpart of project implementer;
- $AFInv_p$ – Amazon Fund Support (numeric): Investment requested to be effectively financed by the Amazon Fund by project;
- Estimation Completion Data (numeric): Estimated duration of the project from the date that the project was signed
- Date approved (date): Date of approval in the Amazon Fund;
- Date awarded (date): Contracted date, starting the project execution and the disbursements;
- Project disbursements (numeric / date): One column for the first disbursement, another for the date, another for the 2nd disbursement and the date of the second disbursement, and so on;

- Des_{pt} - Project disbursements per year (numeric): Calculated variables with ten columns representing the consolidated yearly disbursements:

$$D_{pt} = \sum_{\substack{p=1 \\ y=2008}}^{\substack{p=96 \\ a=2017}} d_{pt}$$

Where D is the disbursements for the project p, $p \in \{1, 2, \ldots, 96\}$ represents the 96 approved projects from Amazon Fund in the year t, and $t \in \{2008, 2009, \ldots, 2017\}$.

Project Management	Interstate Agricultural Development Association - ADAI
Territorial Scope	Communities in areas of influence of hydroelectric projects in the states of Pará, Mato Grosso, Rondônia and Tocantins
Beneficiary	Riverine and agricultural households in areas of influence of hydroelectric projects, which live in rural properties under four fiscal modules
Objective	Implement family units of agroecological production, contributing to food security and income generation in an environmentally sustainable way of riverine and family farmers.
Total Cost of the Project	R$ 9,075,000.00
Amazon Fund Support	**R$ 9,075,000.00 (US$ 3,598,913.89)**
Estimated Completion Date	**36 months** (from the date the contract was signed)

Progress of the project	
Date approved	5.24.2017
Date awarded	**7.31.2017**
1st disbursement on 8.23.2017	R$ 804,567.35
Total amount disbursed	**R$ 804,567.35**
Total amount disbursed in relation to the Amazon Fund's support	**9%**

Figure 10 Individual Project Page on Amazon Fund website

Field Collection with BNDES: The second step to structure the database as described in Figure 9 to model the database regarding Figure 8 is have detailed information about the projects not available on websites or Amazon Fund reports. At the project level information, the Amazon Fund website has only the supported amount per project, lacking information of how much was committed for each Main Component. A contact was made with the BNDES, manager of the Amazon Fund. In response to the request, the BNDES sent a spreadsheet with the data dividing the investments of each Amazon Fund project by Main Component. Thus, the following variables were added to each project:

- Per project support to Main Component 1 (numeric): - per project amount committed to the Promotion of Sustainable Production Activities;
- Per project support to Main Component 2 (numeric): - per project amount committed to the Land Tenure Regularization;
- Per project support to Main Component 3 (numeric): - per project amount committed to the Monitoring and Control;
- Per project support to Main Component 4 (numeric): - per project amount committed to the Scientific and Technological Development.

The sum of the values of these four columns should be the same as the variable AFS_p – Amazon Fund Support. This completes the database structuring for the LEVEL I – Projects, highlighted in Figure, in which there are 96 lines in the database, one for each approved project, and several columns with the variables that will be used.

Figure 11 Database structured at Level I - Projects

Determination of the municipalities covered by each Amazon Fund project: The third step to structure the database as described in Figure 9 to model the database regarding Figure 8 is to define which municipalities are encompassed by each project. It is verified that detailed and reliable information of the projects of the Amazon Fund at the municipal level are at the heart of the construction of the database of this research. In contrast, the information that the Amazon Fund provides in its annual activity reports and on its website are at the level of projects, which commonly cover several municipalities.

One of the great challenges of this research is the construction of a database that determines which municipalities should be considered by project, since the vast majority of them cover areas like watersheds, indigenous territories or environmental conservation units. For example, which municipalities should be considered in a project encompassing protected areas in the northwestern state of Pará? For this, a decision-making process based on the bibliographic study on environmental policies and in the definition of rules on which municipalities should cover each project of the Amazon Fund is proposed.

The decision-making rules about what municipalities are to contemplate each project are presented in Diagram 1, showing which rule was applied in each of the 96 projects. In the diagram, the projects are denominated by acronyms: PR1 - Project 1, PR2 - Project 2, and so on. The list with the 96 projects is in at the end of this supplements.

In support of the rules of Diagram 1, the following data sources were used to determine the municipalities:

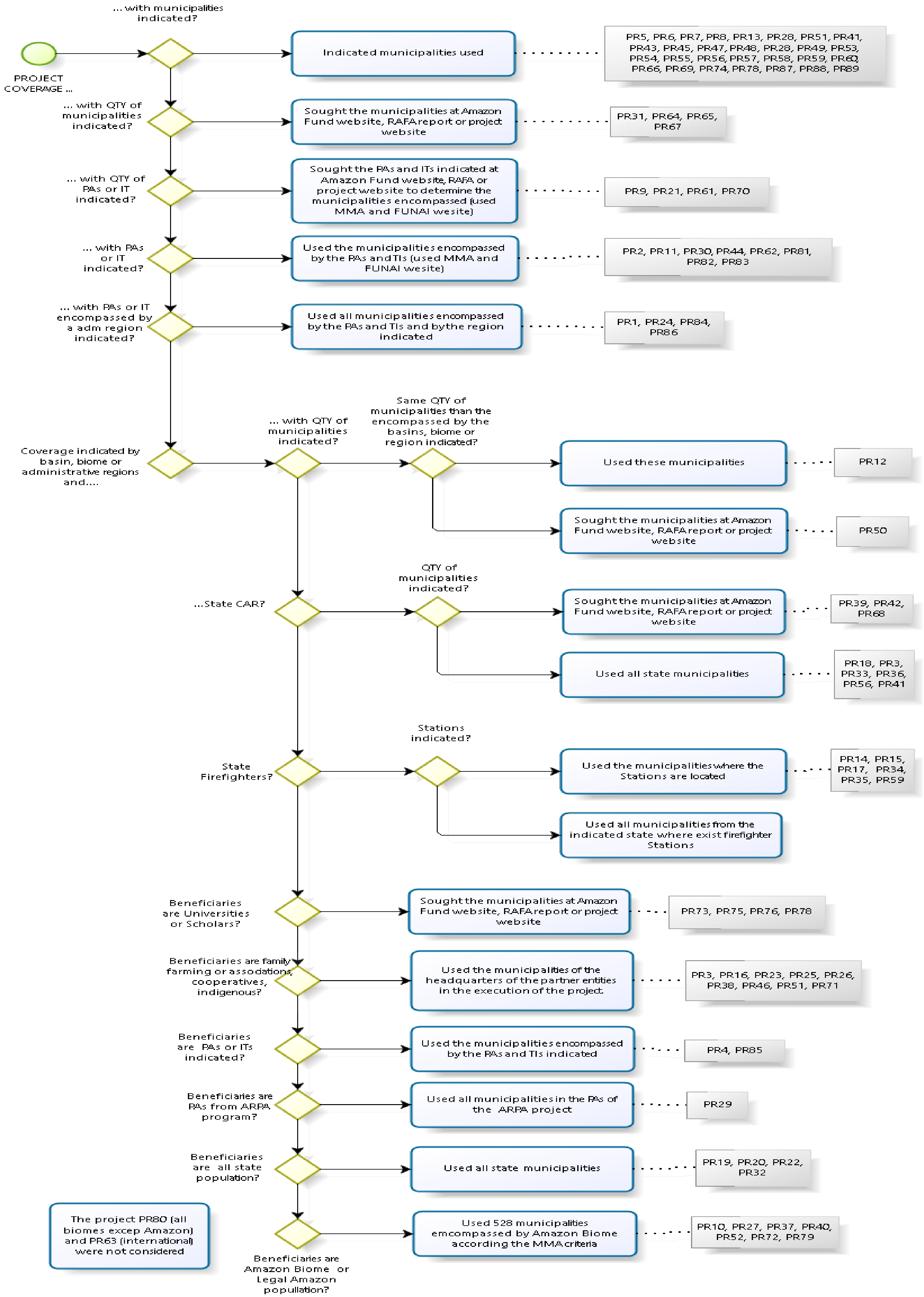
PROJECT COVERAGE ...
... with municipalities indicated?
Indicated municipalities used
PR5, PR6, PR7, PR8, PR13, PR28, PR51, PR41, PR43, PR45, PR47, PR48, PR28, PR49, PR53, PR54, PR55, PR56, PR57, PR58, PR59, PR60, PR66, PR69, PR74, PR78, PR87, PR88, PR89
... with QTY of municipalities indicated?
Sought the municipalities at Amazon Fund website, RAFA report or project website
PR31, PR64, PR65, PR67
... with QTY of PAs or IT indicated?
Sought the PAs and ITs indicated at Amazon Fund website, RAFA or project website to determine the municipalities encompassed (used MMA and FUNAI wesite)
PR9, PR21, PR61, PR70
... with PAs or IT indicated?
Used the municipalities encompassed by the PAs and TIs (used MMA and FUNAI wesite)
PR2, PR11, PR30, PR44, PR62, PR81, PR82, PR83
... with PAs or IT encompassed by a adm region indicated?
Used all municipalities encompassed by the PAs and TIs and by the region indicated
PR1, PR24, PR84, PR86
Coverage indicated by basin, biome or administrative regions and....
... with QTY of municipalities indicated?
Same QTY of municipalities than the encompassed by the basins, biome or region indicated?
Used these municipalities
PR12
Sought the municipalities at Amazon Fund website, RAFA report or project website
PR50
...State CAR?
QTY of municipalities indicated?
Sought the municipalities at Amazon Fund website, RAFA report or project website
PR39, PR42, PR68
Used all state municipalities
PR18, PR3, PR33, PR36, PR56, PR41
State Firefighters?
Stations indicated?
Used the municipalities where the Stations are located
PR14, PR15, PR17, PR34, PR35, PR59
Used all municipalities from the indicated state where exist firefighter Stations
Beneficiaries are Universities or Scholars?
Sought the municipalities at Amazon Fund website, RAFA report or project website
PR73, PR75, PR76, PR78
Beneficiaries are family farming or associations, cooperatives, indigenous?
Used the municipalities of the headquarters of the partner entities in the execution of the project
PR3, PR16, PR23, PR25, PR26, PR38, PR46, PR51, PR71
Beneficiaries are PAs or ITs indicated?
Used the municipalities encompassed by the PAs and TIs indicated
PR4, PR85
Beneficiaries are PAs from ARPA program?
Used all municipalities in the PAs of the ARPA project
PR29
Beneficiaries are all state population?
Used all state municipalities
PR19, PR20, PR22, PR32
The project PR80 (all biomes excep Amazon) and PR63 (international) were not considered
Beneficiaries are Amazon Biome or Legal Amazon popullation?
Used 528 municipalities emcompassed by Amazon Biome according the MMA criteria
PR10, PR27, PR37, PR40, PR52, PR72, PR79

Diagram 1

Table 2 Municipalities data source

INFORMATION	SOURCE	RESPONSIBLE ENTITY	PERIOD
Amazon Biome Municipalities	Ordinance n. 96 MMA 03/27/2008	Ministry of Environment-MMA	2008
Municipalities encompassed by Protected Areas	CNUC -Protected Areas National Registry	Ministry of Environment-MMA	2015
Municipalities encompassed by Indigenous Territories	Indigenous Territories National Registry	Indigenous National Foundation - FUNAI	2015
Municipalities from the administrative regions of Alto Acre, Baixo Acre and Purus	Acre in Numbers Report	Planning State Secretariat from - SEPLAM, state government of Acre	2013
Municipalities per Brazilian States	City System	Geographic and Statistic Brazilian Institute - IBGE	2015
Protected Areas Supported by ARPA Project	ARPA spreadsheet	Amazon Protected Areas Program - ARPA, Ministry of Environment - MMA	2015
Municipalities encompassed by State Protected Areas of Pará in the North Channel of the Amazon River	Report State Protected Areas of Para in the North Channel of the Amazon River	Institute of Man and Environment of the Amazon – IMAZON Geographic and Statistic Brazilian Institute - IBGE	2013
Green Municipalities Program of Pará	Website with the enrolled municipalities	Green Municipalities State Secretariat - SEPMV, state government of Pará	2017
Headquarters municipalities of associations and entities partners for the implementation of projects	Amazon Fund Annual Report - RAFA	National Bank of Socio-Economic Development - BNDES	2010, 2011, 2012, 2013, 2014
Municipalities encompassed by Amazon Fund projects	Amazon Fund Annual Website and annual Report - RAFA	National Bank of Socio-Economic Development - BNDES	2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017
List of critical municipalities for deforestation	Report MMA	Ministry of Environment – MMA	2014
Municipalities encompassed by Amazon Fund projects	Websites from the project managers entities	Several	2017

Thus, after applying the rules of the diagram above, the municipalities covered by each Amazon Fund project were identified.

Municipalities data collection and geospatial data processing: To structure the database as described in Figure 9 to model the database regarding Figure 8, after the determination of the encompassed municipalities by projects identified, additional information must be collected using spatial data, as total area by municipality, areas of the municipality within integral units, sustainable conservation and in indigenous lands, besides information of deforestation by municipality. These data are mainly shapefile and maps format, and a software to processed spatial data (ARCGIS) was used. Thus, the following variables/columns were included in the database:

- A_m – Municipality area (Numeric): Municipalities total area in hectares;
- PAi_m – Integral Protected Areas encompassed by municipalities (Numeric): Municipalities Integral Protected areas in hectares;
- PAs_m - Sustainable Protected Areas encompassed by municipalities (Numeric): Municipalities Sustainable Protected areas in hectares;
- IT_m – Indigenous Territory encompassed by municipalities (Numeric): Municipalities Indigenous Territory areas in hectares
- DE_m – Municipality Deforestation (Numeric): Municipalities deforestation in hectares between 2002-2017

The following data sources were used.

Table 3 Municipalities geospatial information sources

GEOSPATIAL MAP (SHAPES)	RESPONSIBLE ENTITIES	PERIOD
Political Administrative Maps (Municipalities)	Geographic and Statistic Brazilian Institute - IBGE	2014
Legal Amazon Boundaries	Ministry of Environment - MMA	2008
Amazon Biome Boundaries	Ministry of Environment - MMA	2008
Indigenous Territories	Brazilian Environment Institute - IBAMA	2014
Protected Areas	Brazilian Environment Institute - IBAMA	2014
Deforestation	Project for Estimate the Amazon Deforestation – PRODES, developed by the National Institute of Space Research – INPE	2002-2017

As highlighted in Figure 12 there are now hundreds of rows in the database, since there are several municipalities for each of the 96 projects.

Figure 12 Database structured at Level II - Municipalities

Breakdown of main component and activity by municipality: Beyond the project information from the Amazon Fund website, all projects present a tree to show their main components and activities (Figure 13). The next step included the main components and activities by municipality for each project.

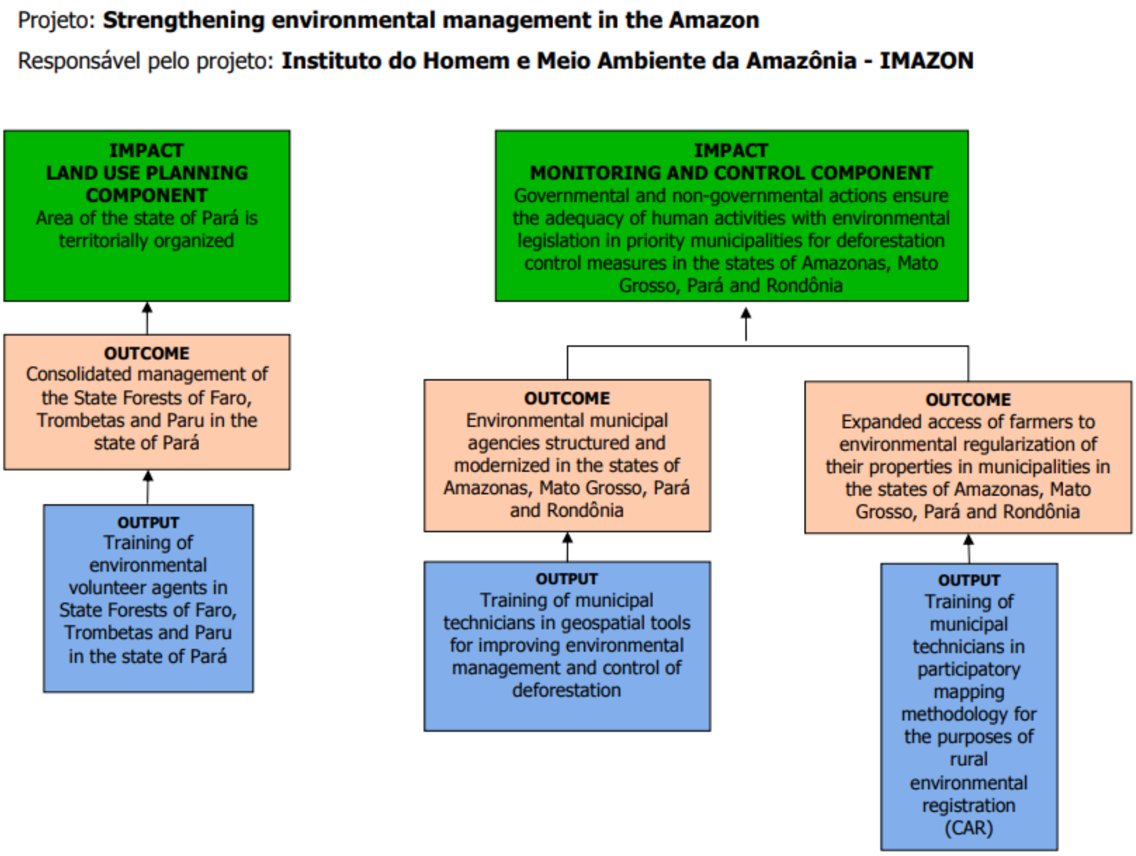

Figure 13 Project Tree

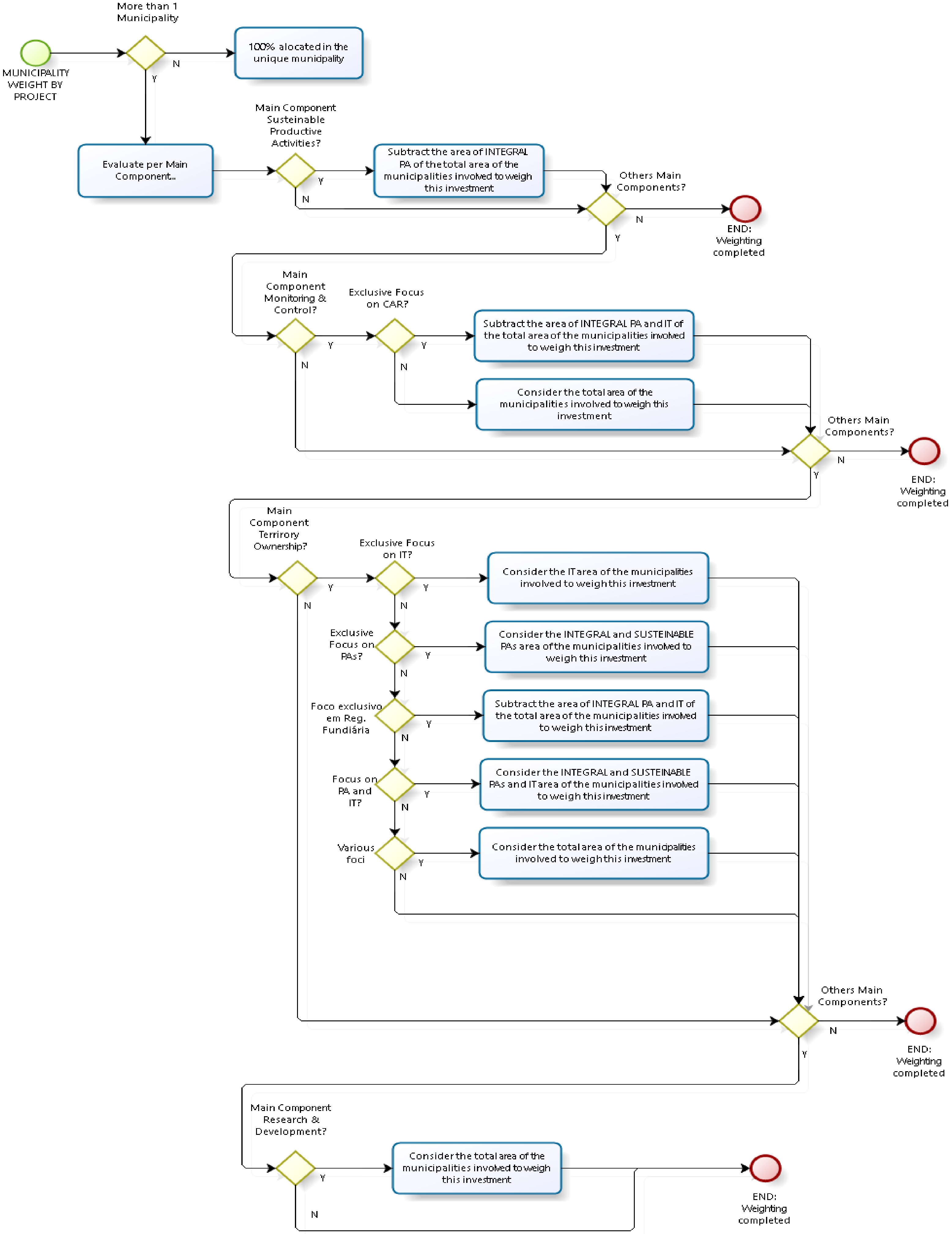
More than 1 Municipality
MUNICIPALITY WEIGHT BY PROJECT
N
Y
100% alocated in the unique municipality
Evaluate per Main Component..
Main Component Susteinable Productive Activities?
Y
N
Subtract the area of INTEGRAL PA of the total area of the municipalities involved to weigh this investment
Others Main Components?
N
Y
END: Weighting completed
Main Component Monitoring & Control?
Exclusive Focus on CAR?
Y
N
Subtract the area of INTEGRAL PA and IT of the total area of the municipalities involved to weigh this investment
Consider the total area of the municipalities involved to weigh this investment
Others Main Components?
N
Y
END: Weighting completed
Main Component Terrirory Ownership?
Exclusive Focus on IT?
Consider the IT area of the municipalities involved to weigh this investment
Exclusive Focus on PAs?
Consider the INTEGRAL and SUSTEINABLE PAs area of the municipalities involved to weigh this investment
Foco exclusivo em Reg. Fundiária
Subtract the area of INTEGRAL PA and IT of the total area of the municipalities involved to weigh this investment
Focus on PA and IT?
Consider the INTEGRAL and SUSTEINABLE PAs and IT area of the municipalities involved to weigh this investment
Various foci
Consider the total area of the municipalities involved to weigh this investment
Others Main Components?
N
Y
END: Weighting completed
Main Component Research & Development?
Y
N
Consider the total area of the municipalities involved to weigh this investment
END: Weighting completed

Diagram 2

Per Main Component, determination of the weight of each municipality: To structure the database as described in Figure 9 regarding Figure 8, the next task is to define the weight to divide the investment received by the projects in the Main Components per municipality. Based on qualitative assessments, it is proposed by this research a decision-make rule to ponder the weight of each municipality in the Main Component, as shown in Diagram 2.

The following variables was added to database LEVEL 3 (Projects ← Municipality ← Main Components per Municipality):

- ω_{pmk}- Project Municipality weight (numeric): Variable that represents the weight with the percentage ratio of representation to be applied in each main component for each municipality covered by a project;
- Des_{pkt} - Annual disbursement by main component (numeric): Variable that represents the annual disbursements already made in each main component for municipality and project covered by a project (2008-2017);
- $AFInv_{pmk}$ - Investment by main component, municipality and project (numeric): Variable that represents the financial amount to be applied in each main component for each municipality covered by a project;
- $AFInv_{m}$ - Investment by municipality (numeric): Variable that represents the entire value of the Amazon Fund to be invested by municipality;
- $AFInv_{mk}$ - Investment by municipality and main component (numeric): Variable that represents the entire value of the Amazon Fund to be invested by municipality

Next, it is shown the algebraic equations used to calculate the new variables proposed with the decision-rules is shown in Diagram 2, where the variable ω_{pmk} represents the percentage ratio (%) for the main component k in the municipality p encompassed by the project p, where $p \in \{1, 2, \ldots, 96\}$. The k represents the Main Component where $k \in \{1, 2, 3,4\}$, and $k = 1$ is used for Sustainable Production

Activities, $k = 2$ for Monitoring & Control, $k = 3$ for Territorial Ownership and $k = 4$ for Scientific and Technological Development. Thus, for $k = 1$

$$\omega_{pm1} = \frac{A_{pm} - PAi_{pm}}{\sum A_{pm} - PAi_{pm}}$$

for $k = 2$, where $CAR = 1$ $represents$ exclusive CAR projects

$$\omega_{pm2_{CAR=0}} = \frac{A_{pm}}{\sum A_{pm}} \quad \cup \quad \omega_{pm2_{CAR=1}} = \frac{A_{pm} - APi_{pm} - IT_{pm}}{\sum A_{pm} - APi_{pm} - IT_{pm}}$$

For $k = 3$, where:

$IT = 1$ represents exclusive Indigenous Territories exclusive project
$PA = 1$ represents exclusive Protect Areas project
$OReg = 1$ represents exclusive Land Ownership regularization projects
$ITPA = 1$ represents exclusive TI ∩ UC projects
$Out = 1$ represents all others projects

$$\omega_{pm3\ IT=1} = \frac{IT_{pm}}{\sum IT_{pm}} \cup \omega_{pm3\ PA=1} = \frac{PAi_{pm} + PAs_{pm}}{\sum PAi_{pm} + PAs_{pm}} \cup \omega_{pm3\ Oreg=1} = \frac{A_{pm} - PAi_{pm} - TI_{pm}}{\sum A_{pm} - PAi_{pm} - TI_{m}} \quad \cup \quad \omega_{pm3\ ITPA=1} = \frac{PAi_{pm} + TI_{pm}}{\sum PAi_{pm} + TI_{pm}} \cup \omega_{pm3\ Out=1} \frac{A_{pm}}{\sum A_{pm}}$$

For $k = 4$

$$\omega_{pm4} = \frac{A_{pm}}{\sum A_{pm}}$$

Where A_{pm} represents the total area in hectares from project m at the municipality m, PAi_{pm} represents the total of Integral Protected Area from project m encompassed by the municipality m, PAs_{pm} represents the total of Sustainable Protected Area from project encompassed by the municipality m, and IT_{pm} represents the total of Indigenous Territory area from project m encompassed by the municipality m.

The calculation of the investment by main component by municipality is then presented where $AFInv_p$ represents the investment of the Amazon Fund in the project p and ω_{pmk} is the percentage ratio weight for the same project in the municipality m and main component k.

$$AFInv_{pmk} = AFInv_p \times \omega_{pmk}$$

The annual disbursement for each Main Component is presented, where Des_{pt} represents the annually disbursement by project and ω_{pmk} is the percentage ratio weight for the same project in the municipality m and Main Component k.

$$Des_{pmkt} = \sum_{\substack{p=1\\m=1\\k=1\\t=2008}}^{\substack{p=96\\m=i\\k=4\\t=2017}} \left(Des_{pt} \times \omega_{pmk}\right)$$

From here, some relevant algebraic variables to answer the questions of this research are proposed. To evaluate the total investment of Amazon Fund in a given municipality and compare it with deforestation, it is suggested to create the variable $FAInv_m$ as described below

$$AFInv_m = \sum_{\substack{p=1\\m=1\\k=1}}^{\substack{k=4\\m=n\\p=96}} \left(AFInv_{pmk}\right)$$

The sum of the investment of all Amazon Fund projects by main component is also relevant to evaluate the most effective projects in relation to municipal deforestation. Thus, the investment by main component by municipality 〖ICP〗 is described below:

$$AFInv_{mk} = \sum_{p=1}^{96} (AFInv_m \times \omega_{pmk})$$

All these new calculated variables were added in the database. The database now has tens of thousands of rows considering the new variables for the LEVEL III - Main Component.

Determination of the weight of each main component by activity: No data are available for the specific component in the BNDES publications or in the field collections of this research. Thus, for the calculation of investment of the Amazon Fund in these components the author adopted the premise of dividing the investment in the municipality Main Components equally among the specific objectives linked to it.

The following variables were added in the database columns for each specific component:

- $FAInv_{pmks}$ - Investment by specific component (numeric): Variable that represents the financial amount to be applied in each specific component for main component for each municipality covered by a project;
- Des_{pmks} - Annual disbursement by specific component (numeric): Variable that represents the annual disbursements already made in each specific component for each main component, municipality and project covered by a project (2008-2018).

Is shown the algebraic form of $FAInv_{pmks}$ is shown below, where Q is the quantity of specific components and s represents the type of the specific component:

$$FAInv_{pmks} = \frac{FAInv_{pmk}}{Q}$$

Finally, the algebraic form of Des_{pmks} is shown

$$Des_{pmks} = \frac{Des_{pmkt}}{Q}$$

After the new rows and variables added from the development that happen at LEVEL III and IV, the final database structure is shown in Figure 14.

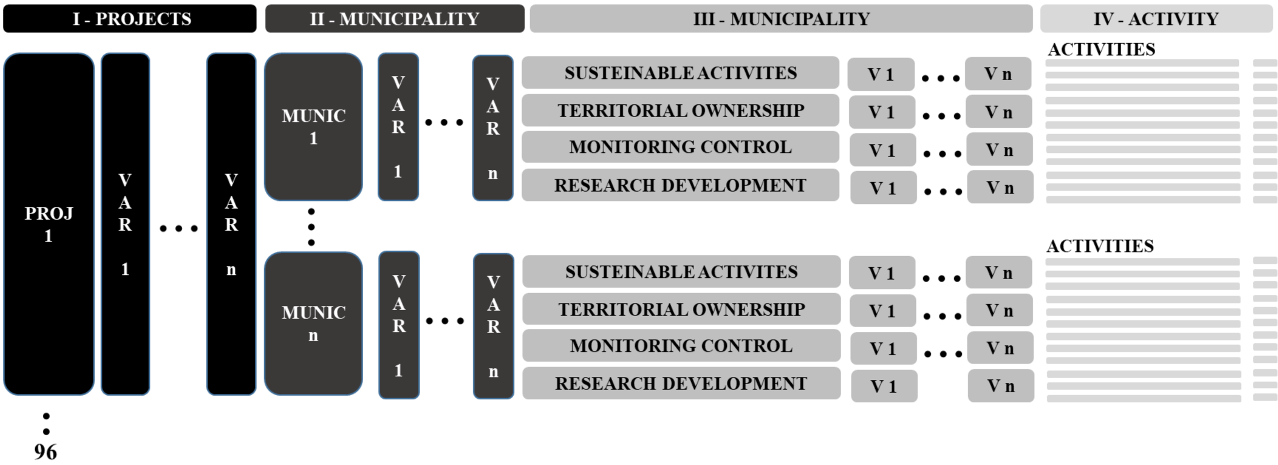

Figure 14 Final Database Structured

Limitations and considerations

The data used to build the database were collected in the **Portuguese version** of Amazon Fund website and in the **Portuguese version** of Amazon Fund Annual Reports – RAFA. The Amazon Fund currency base is the Brazilian Real. The donations received in foreign currency are exchanged for the Brazilian currency as soon them are received by the exchange rate of the day, the projects disbursements are done in Brazilian currency and all audits happen at this currency. For the reports and publications in English, the Amazon Fund convert the subsidized and disbursed amounts using the conversion rate of the day when each respective project was approved. The official exchange rates are collected from the Brazilian Central Bank. (Amazon Fund). This study used the same methodology.

For the Brazilian governmental agencies INPE, CENSIPAM and IBAMA with accountability in Brazilian Reais, this study used an average exchange rate among 2009 to 2017 aiming reduce the exchange rate interference in the historical trend evaluation.

Due to information gaps between the field surveys carried out by the BNDES and the information available on the Amazon Fund website, some premises are identified for the assembly of this database, as shown in Table 4.

Table 4 Research assumptions in response at divergences / limitations of data collection

There is no value per principal component in field collection with BNDES	The value per main component from the field research at the BNDES worksheet were divided into 2 rows, inside and outside Amazon Biome	Project has more than 1 main component, with some of them ignored in the BNDES field collection	Project Name	Project Number	Author Premises
X			Sustainable Indigenous Amazon Project	2	Prorated 80% for the Main Component "Susteinable Activities" and 20% for "Terrirorial Ownership"
X			High Juruá	4	Prorated 80% for the Main Component "Susteinable Activities" and 20% for "Terrirorial Ownership"
X			Amazonia SAR	10	Prorated 80% for the Main Component "Monitoring & Control" and 20% for "P&D"
X			Value Chains in Indigenous Lands in Acre	11	100% on "Susteinable Acritivities", unique Main Component
X			Amazon Integrated Project	16	100% for "P&D", unique Main Component
			Sustainable Mato Grosso	21	Small divergence of R$0,4
		X	Banco do Brasil Foundation - Amazon Fund	26	Considering the value of the field research at the BNDES worksheet that considers 100% in the "Sustainable Activities" component, ignoring "Territorial Planning", "Monitoring & Control" and "Scientific Development" provided by the Amazon Fund website
			Agroforesty business - Jari		Project considered Canceled...
X			CAR Bahia	31	100% on "Monitoring & Control", unique Main Component
	X		CAR Tocantins	36	The prorated per Main Component was calculated considering the sum of the values inside and outside the Amazon Biome
X			Strengthening environmental management in the Amazon	38	Prorated 40% for the Main Component "Monitoring & Control", 40% for "Territorial Ownership" and 20% for "P&D"
X			Sustainable Bem Viver	44	Prorated 50% for the Main Component "Susteinable Activities" and 50% for "Terrirorial Ownership"
		X	IREHI – Taking Care of Territory	61	Considering the value of the field research at the BNDES worksheet that considers 100% in the "Sustainable Activities" component, ignoring "Territorial Ownership provided by the Amazon Fund website
		X	ARAPAIMA: Production Networks	62	Considering the value of the field research at the BNDES worksheet that considers 100% in the "Sustainable Activities" component, ignoring "Territorial Planning" provided by the Amazon Fund website
		X	Sustainable Environmental Management of Indigenous Lands in the State of Amazonas	65	Considering the value of the field research at the BNDES worksheet that considers 100% in the "Territorial Ownership" component, ignoring "Susteinable Acritivities" provided by the Amazon Fund website
		X	Strengthening Territorial and Environmental Management of Indigenous Land in the Amazon	70	Considering the value of the field research at the BNDES worksheet that considers 100% in the "Territorial Ownership" component, ignoring "Susteinable Acritivities" provided by the Amazon Fund website
X			Fruits from the Forest	71	100% on "Susteinable Acritivities", unique Main Component
X			Environmental Monitoring of Brazilian Biomes	80	Prorated 80% for the Main Component "Monitoring & Control" and 20% for "P&D"
X			Management and governance at Rio Negro Basin and Xingu - PGTAs	81	Prorated 50% for the Main Component "Susteinable Activities" and 50% for "Terrirorial Ownership"
X			Indigenous Territorial Management in the South of Amazonas State	82	Prorated 50% for the Main Component "Susteinable Activities" and 50% for "Terrirorial Ownership"
X			Consolidating Territorial and Environmental Management in Indigenous Lands	83	Prorated 50% for the Main Component "Susteinable Activities" and 50% for "Terrirorial Ownership"
X			Bolsa Floresta+	84	Prorated with same values than the Bolsa Floresta phase 1 Project
X			Valuable Forests - New business models for the Amazon	85	100% on "Susteinable Acritivities", unique Main Component
X			Communal Forests	86	100% on "Susteinable Acritivities", unique Main Component
X			Use of social technologies to reduce deforestation	87	100% on "Susteinable Acritivities", unique Main Component
X			Sustainable Tapajós	88	Prorated 90% for the Main Component "Susteinable Activities" and 10% for "Terrirorial Ownership"
X			Adding Value to Amazonian Socioproductive Chains	89	
X			Everlasting Forest	90	Prorated 90% for the Main Component "Susteinable Activities" and 10% for "R&D"
X			Sowing Rondônia	91	Prorated 80% for the Main Component "Susteinable Activities" and 20% for "Monitoring & Control"
X			Preserving the Babassu Forest	92	100% on "Susteinable Acritivities", unique Main Component
X			Forest Cities	93	Prorated 90% for the Main Component "Susteinable Activities" and 10% for "R&D"

4 Landing REDD+ at subnational level: impact analysis of Alta Floresta, Brazil

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Abstract: Rewarding Brazil for a sharp reduction in Amazonian deforestation rates during the early 2000s, Norway and Germany donated US$1.2 billion in between 2008 and 2017 to the Amazon Fund to support policies aiming at reducing emissions from deforestation and forest degradation (REDD+) in Brazil. The Amazon Fund has, in turn, invested in a suite of activities including projects designed to avoid deforestation and, more generally, to promote the conservation of the Amazon Biome. Among all of the Amazon Fund investments (Correa et al. 2018), the Olhos D'Água da Amazônia Project is the best example of project promoting enabling REDD+ policies at municipality level that work directly with the main drivers of deforestation, i.e., small and medium-sized crop and livestock producers. This project is often cited as one of the main success stories of the Amazon Fund that met all its targets in a cost-effective way. However, to assess a REDD+ project it is necessary to consider its environmental additionality in relation to a counter-factual scenario using a control group. In order to achieve this, this paper analyzes the impacts of the Olhos D'Água project on deforestation in Alta Floresta, as well as on intermediary outcomes that impact land use decisions: the growth of rural environmental registries (CAR) and property certifications by the National Institute for Colonization and Agrarian Reform (INCRA) as well as changes in milk and honey outputs that received direct support. In order to assess the impact of the Olhos D'Água project in Alta Floresta we employ the synthetic control methodology: we create a weighted match from the pool of possibly-most-comparable municipalities that best resembles pre-treatment outcomes in Alta Floresta. Treatment effects are measured as the difference in post-treatment outcomes between Alta Floresta and the synthetic control. Field interviews and official projects support our statistical matching process. On the one hand, the results indicate that in the years following the implementation of the project (2011-2016) there has been a statistically robust jump in CAR registries after treatment, as well as increases in INCRA certifications, what helped the municipality to get removed from the blacklist, at least, in a shorter period than would be in the absence of the project. Further, we see moderate positive effects on honey and milk production for the period 2014-2016. On the other hand, our synthetic matching is less precise for the forest outcome, as it shows no significant reduction in forest loss, though the project may have helped hold it steady. In any case it should be highlighted that many of the effects of the Olhos D'Água project may still be observed in the long run. While providing an in-depth analysis of a jurisdictional REDD+ the article concludes by pointing out to the importance of conducting rigorous impact analysis of REDD+ in order to ensure its continuous improvement over time.

Keywords: Forest conservation policy, enabling mechanism, REDD+, Amazon Fund, impact evaluation, quasi-experimental methods, synthetic control method

1. Introduction

With increased attention to reductions in emissions from deforestation and forest degradation (REDD+) after the Paris agreement in 2015 and the consequent increase in voluntary international financing, the Results-Based Funding has become an important instrument for channeling financial resources to forest conservation projects (Angelsen 2017; Carvalho 2012; Turnhout et al. 2017; van der Hoff et al. 2015). Established in 2008 by the Brazilian Government, the Amazon Fund is the world's largest REDD+ program based on Results-Based Funding, but scholars have raised concerns about the lack of evidence of the effectiveness of Amazon Fund (Eldridge and Palmer 2009; Forstater, Nakhooda, and Watson 2013; Hood and Peters 2004; Marcovitch and Pinsky 2014; van der Hoff, Rajão, and Leroy 2018; Wolosin, Breitfeller, and Schaap 2016). Ferraro (2009) depict that much of what is called evaluation of environmental program impact is simply monitoring of indicators lacking clear theories of causal relationships, not assessing the degree to which changes in outcomes can be attributed to the program rather than to confounding factors that also affect the outcomes.

For an effective evaluation of an environmental program, such as the as Amazon Fund, Correa et al. (2018) highlighted the necessity to evaluate the individual impact evaluations of the supported projects. A counterfactual impact evaluation can isolate rival impact theories, which arise due to diversity of confounding factors. e.g. While Amazon Fund disbursements for its supported projects were in average under USD 50 million/year between 2008-2017 in an extensive and socio-economic diverse area as the Amazon Biome, Brazil spends more than USD 1 billion/year on forest conservation policies only at the federal level (Cunha et al. 2016), offered more than 60 billion/year of rural credit to agriculture support (MAPA 2018), beyond of several parallel initiatives occurring in the same area funded by other sources of financing, as World Bank.

For the monitoring of its performance, the Amazon Fund reports comprehensive data related to the public policies to which the Fund aims to contribute and publish project performance indicators, composed of auditable data collected in the field and completed by the beneficiaries of each project arguing that project performance indicators reflect their contribution to national forest policies. Several scholars highlight the lack of a clear link between 'project performance' as assessed within Amazon Fund and actual impact on deforestation rates (Eldridge and Palmer 2009; Marcovitch and Pinsky 2014; Correa et al. 2018; Forstater, Nakhooda, and Watson 2013; Lee et al. 2015; van der Hoff, Rajão, and Leroy 2018; van der Hoff et al. 2015; Simonet et al. 2018).

Among all of the Amazon Fund investments (Correa et al. 2018), the project Olhos D'Água da Amazônia in Alta Floresta is the best example of project promoting enabling REDD+ policies at municipality level that work directly with the main drivers of deforestation, i.e., small and medium-sized crop and livestock producers. In 2009 the municipal government created the project Olhos D'Água in order to attain environmental compliance and be removed from the blacklist of deforestation (see section 2). The project is often cited as one of the main success stories of the Amazon Fund, that during the two phases of the project met all its targets in a cost-effective way. However, in order to assess a REDD+ project is necessary to consider its environmental additionality in relation to either a counter-factual scenario using a control group.

In order to achieve this, this paper analyzes the impacts of the Olhos D'Água project in the deforestation of Alta Floresta using the others blacklisted municipalities like control group, as well as on intermediary outcomes that impact land use decisions: the growth of rural environmental registries (CAR) and property certifications by the National Institute for Colonization and Agrarian Reform (INCRA) as well as changes in milk and honey outputs that received direct support.

The effects of the Olhos D'Água project is evaluated using the synthetic control methodology. Having only one 'treated' political unit, Alta Floresta, is construct a 'Synthetic Alta Floresta' from a pool of controls which resembles the path of the real unit before the intervention. Impacts are then measured as the distance in outcomes between both units after treatment. The empirical results are complemented with a detailed qualitative research. We analyze project documentation, the Alta Floresta municipality's official project reports, included the external evaluation conducted by GIZ (German Agency for International Cooperation) (SECMA 2013, 2016; GIZ 2016).

The rest of this paper is as follows. Section 2 presents the Olhos D'Água project including various contextual points. Section 3 presents our evaluation methodology. Section 4 explains the data and how we processed it. Our results are then presented in Section 5 and discussed in Section 6.

2. Policy intervention and background

Between 2004 and 2012, Brazil managed to reduce its deforestation rates by 80%. Researchers attribute the decline to Brazil's paradigm shift during the early 2000s (Pan et al. 2011; Rajão, Azevedo, and Stabile 2012; Sitch et al. 2005). Large impacts are attributed to federal government initiatives like the expansion of the protected area system, to the establishment of a live deforestation monitoring system (DETER), an increased financing of the environmental enforcement agency (IBAMA), and the restriction of public credit to environmental offenders. Furthermore, state government initiatives like the rural environmental cadaster (CAR), while not reducing deforestation systematically on the short term, could provide the basis for a stronger environmental governance (Costa et al. 2018; Gibbs et al. 2015; Nepstad et al. 2014).

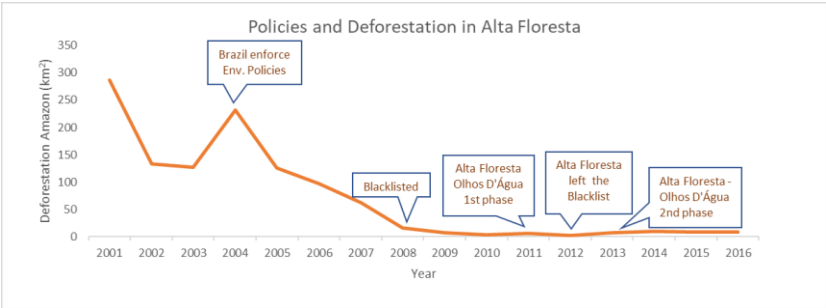
Another successful policy became known informally as the "blacklist" (Arima et al. 2014a; Cisneros, Zhou, and Börner 2015) when federal government cracked down on deforestation in local level and published a decree creating a list of municipalities with the largest accumulated deforested area in the prior three years, plus increases in deforestation in at least three of the prior 5 years (MMA 2007). The decree revoked the property registration certificate of rural properties with georeferenced certifications not updated in INCRA (in Portuguese, the National Institute for Colonization and Agrarian Reform), effectively blocking both their access to government agricultural credit and their right to sell or transfer land by inheritance.

Furthermore, in order to avoid co-responsibilities and reputational damage, slaughterhouses, supermarket chains and other companies started avoiding buying soy and livestock production from the blacklisted municipalities (Decree n. 6321 2007). To be removed from the list, a municipality must satisfy three requirements: reduce deforestation rates to under 40km2 per year; register at least 80% of eligible area in the rural environmental register (CAR);

and achieve a 60% fall in deforestation rates over three years (Decree 6321/2007 and Ordinances 28/2008, 102/2009, 67/2010, 138/2011, 139/2011, 175/2011, 187/2012, 323/2012, 324/2012, 412/2013 2010).

These initiatives had impacts in Alta Floresta − even though when the blacklist was established, Alta Floresta had already substantially reduced deforestation from over 100 to below 40 km² /year. (Figure 1). It was in response to these regulatory challenges that the Municipality of Alta Floresta sought in 2010 the support of the Amazon Fund for the realization of the project Olhos d'Água da Amazônia.

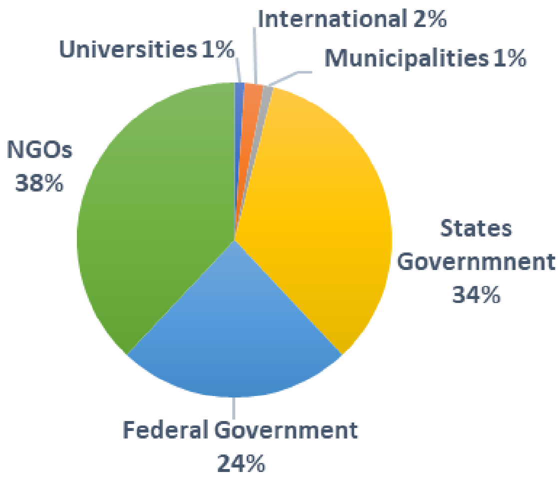
Figure. 1 Relevant Policies and Deforestation Outcomes over time in Alta Floresta



2.1 Olhos D'Água da Amazônia

By December 2017, 667 million USD of the 1.22 billion USD in donations to the Amazon Fund have been committed to subsidize 96 projects. The most of these grants (approx. 58%) went to federal and state governments for related efforts such as improvements in deforestation monitoring by satellite, implementation of the rural environmental register (CAR), and operational command-and-control activities. Conservation projects by NGOs represented another 38% of the committed amounts with approved projects by the Amazon Fund. Most were integrated conservation and development projects aiming to provide socio-economic alternatives to increase income and quality of life for traditional and indigenous populations within conservation units (protected areas with varied types of limits). Of the 772 municipalities in the Legal Amazon, six sought the support of Amazon Fund and had projects approved. This involved 7.8 million USD, less than 1% of all funds. (BNDES 2018).

Figure. 2 Shares of Amazon Fund commitments by Implementer Classification (BNDES 2018)



Via the two projects, Olhos D'Água I and II, Alta Floresta received 4.9 million USD, representing 65.2% of funds disbursed at the municipality level. The projects aimed to lower deforestation rates by bringing together public stakeholders with small- and middle-sized cattle ranchers and soybean farmers (Figure 2). The project Olhos D'Água provides a good example of what could be achieved in other similar municipalities. As many other municipalities across the Amazon, the economy of Alta Floresta around agriculture, livestock, mining and logging − factors historically among the main drivers of deforestation. Furthermore, the local mindset still views deforestation as synonymous to development as a consequence of the 1970s federal policies that aimed to occupy and colonize the Amazon, plus the private company that founded the city (Hayes and Rajão 2011; Rajão and Vurdubakis 2013). All the above indicates that an in-depth analysis of Alta Floresta can provide important insights to other subnational REDD+ in Brazil and abroad.

2.1.1 Phase 1 (March 2011 - December 2013)

The Amazon Fund supported the implementation of the 1st phase of this project with 2.78 million Reais (1.58 Million USD) between March of 2011 and December 2013, aiming to strengthen local municipal environmental management through the acquisition and contracting of specialized employees, computers, GPS devices and GIS software (SECMA 2013, 2016). The project also aimed to carry out the certification of land tenure through the geo-referencing of rural properties within the Alta Floresta municipality. For that, the Olhos D'Água project team were trained in geoprocessing techniques and in how to prepare the portfolio of documents required by INCRA to issue such georeferenced certifications. An agreement between the municipality and INCRA was signed to streamline the procedures and GPS devices were used to georeferenced perimeters. In this way, a process that can cost more than USD 10 thousand became free of charge to land holders.

The project resulted in the geo-referencing of over 1,200 property perimeters, and some of them which were submitted to INCRA to proceed with the official legalization of their land holdings. The property boundaries obtained for INCRA were also used as the starting point for CAR registry, which in addition requires the delimitation of water springs, permanent protection areas and legal reserves. These were conducted by technicians of the Olhos D'Água project in collaboration with UNEMAT, the Mato Grosso State University (SECMA 2013). The project technicians furthermore helped land holders to prepare all required documents for a CAR registry and to submit them to the State Environment Secretariat of Mato Grosso (SEMA). SECMA did not refuse registries without a full compliance of environmental rules, though land holders had to formally commit to a schedule to restore degraded areas. The project resulted in 2,040 CAR submissions for 2,801 properties (SECMA 2013; GIZ 2016)

Olhos D'Água further aimed to support sustainable production activities as way to indirectly incentivized deforestation reduction. Different studies have proposed that agricultural intensification may lead to conservation, a theory also known as "land sparing". While still controversial and largely untested, land sparring has become a mainstream strategy in the Amazon (Merry and Soares-Filho 2017). In the case of Alta Floresta, the Olhos D'Água project stimulated improvements in milk production and the introduction of honey production in, until then, "unproductive" forested areas.

Alta Floresta has two seasons for the milk production, the dry and the rainy. Due to the loss of nutrients by pasture rudimentary management, the yield difference in milk production between these seasons is up to 50%. In the first phase the project Olhos D`Água selected 20 farms as demonstration units that also function as regional training centers to test learned techniques on the ground. In collaboration with universities, NGOs and the Brazilian Enterprise for Agrarian Research (EMBRAPA), the project reported that carried out inside the demonstration units the implantation of techniques for rotational pasture and installation of fences, soil evaluation and application of fertilizers, installation of irrigation systems and the supply of nutritional supplements for cattle, equaling the milk production for the two seasons.

With a higher productivity granted by the program, farmers were stimulated to change the land use of parts of their properties in order to comply with the Forest Code. In particular, farmers where trained on restoration techniques to recovery of degraded areas committed when the properties enrolled their properties in CAR, such as planting of seeds and fencing the springs, riparian forests, legal reserves (percentage of up to 80% of the property that must be set aside to native forest) and preventing degradation by livestock.

Restoration efforts with project support also flowed to outside the demonstration unites, making donations of half the logs, fences and seeds a necessity for small ranchers with properties with size less than 55 ha. (SECMA 2013; GIZ 2016; BNDES 2017).

Thanks to the efforts coordinated by the Olhos D'Água project the municipality of Alta Floresta was taken off of the blacklist in 2012. By that year 2,801 rural properties had been registered in CAR totalizing 82% of the area of the municipality. Furthermore 1,738 ha of Permanent Protected Areas was reforested, 1,720 farmers trained in agroforestry systems; and pasture management applied in 20 pilot selected farms. Given that achievement of the main initial goal of the project, Phase 1 of the project had been finished by December of 2013 (SECMA 2013; GIZ 2016; BNDES 2017).

2.1.2 Phase 2 (September 2013 - June 2016)

The Amazon Fund supported the implementation of the 2nd phase with 3.33 million USD between October of 2013 and June 2016. The project continued to support the georeferenced certification of land holdings at INCRA. By the time INCRA had reformed the registration process to a simpler system, called Land Management System (SIGEF). Thereby Olhos D'Água reported an additional 530 georeferenced registrations (i.e., beyond the 1,220 in Phase 1). (SECMA 2016; GIZ 2016; BNDES 2017)

One of the main activities of the second phase was to make the necessary adjustments to migrate the CAR under the new Forest Code. CAR has been created in Mato Grosso and Pará back in 2009 (inspired in a system from the former created in 1999), but became the backbone of the new forest law approved in 2012. In this way the state governments had to migrate to a new system under the management of the Brazilian Forest Services (SFB) agency. In addition, the second phase of the project motivated aimed at committing landholders to initiate the forest restoration actions required for environmental compliance. With this purpose the project included donations of logs, fences and seeds, to restore degraded areas for small properties (i.e. under 400 ha). (SECMA 2016; GIZ 2016; BNDES 2017).

For the further development of sustainable production, in the second phase the project speeded up these initiatives to additional 20 demonstrative units. While maintaining a focus on dairy, more restrictive rules were established. Property owners now had to provide the manpower for pasture management, live on the farm, and the farm size was limited to 400 ha. The project added actions as supply of veterinary inputs to control diseases, as well carried out 10 workshops, 7 practical field workshops, 10 speeches and 30 technical visits to improve the cattle quality with artificial insemination and good practices for the milk production, highlighting an increase of 51% in the milk production at the demonstrative unit selected to be monitored

Phase 2 more specifically aimed to develop honey production in Alta Floresta. During the phase I, one of the demonstrative units had a honey production plant in operation, what got the attention of ranchers, and this was sought in this phase of the project. The project acquired 300 beehive boxes and built a municipal honey facility by the end of 2013. With an additional contribution from the municipality, the project acquired another 300 beehive boxes to boost the internal box productions, and donated 381 hives to 64 farms between August 2014 and March 2016. To receive a hive, a farm needed to have adhered to CAR and signed a commitment to the restoration of degraded areas, as well as to attend training by the project team. In sustainable production beyond honey, Phase 2 also dug 80 fish tanks and gave seeds and tools to start vegetable production in farms (SECMA 2016; GIZ 2016; BNDES 2017).

A new initiative for the Olhos D'Água project within Phase 2 was the 'Water Guardian' program. For this new program, the project paid R$240 per ha per year during a two-year period to family agriculture properties located in the Mariana I/II basins, which affect Alta Floresta's water supply. Enrollment in this program was voluntary but restricted to farms which updated their environmental status within the CAR system and committed to the maintenance or restoration of riparian forests, with the monitoring realized by the municipality forest engineers. Over half of the eligible farms enrolled in this program. Several small properties under 1 ha did not (SECMA 2016; GIZ 2016; BNDES 2017). The Water Guardian program is in some respect similar to a Payments for Environmental Services (PES) scheme, nonetheless it is limited due to the brief time period, the unclear definition of the contracted environmental service and the lack of a monitoring and sanctioning mechanism (Wunder 2007; Wunder, Engel, and Pagiola 2008).

It is clear that the phases I and II of the Olhos D'Água project delivered its proposed objectives. Also, given the relatively modest amount invested in the municipality and the substantial results it obtained, it is not surprising that the project is considered one of the main success stories of the Amazon Fund. However, the achievement of pre-defined targets should not be considered the only measure of success. Instead it is important to evaluate also the impact of Olhos D'Água, namely, the additional environmental benefits brought by the projects in comparison to a control group that did not receive the same levels of funding. The next section presents the synthetic control method and discusses the results obtained in the municipality of Alta Floresta in relation to REDD+ objectives.

2.2. Theory of Change

The structure and aims of the Olhos D'Água project commitment to a multiple intervention strategy that traces improvements in environmental governance, land tenure and agricultural intensification as leading to deforestation reductions. Along with the challenge to reduce deforestation rates, the registry of land holdings within CAR became a major obstacle to exit the blacklist. CAR is part of the intended implementation of the Brazilian Forest Code and requires all land holders to register their land in a geo-spatial database. The CAR supplements the existing property regulations of the National Institute of Colonization and Agrarian Reform (INCRA). For the first time, CAR would make it possible for government agencies to identify the perpetrators of deforestation and monitor whether individual landowners were complying with the Forest Code. The CAR enrolment itself does not require compliance with environmental laws, though it does require a restoration plan for how and when a property will become compliant in the next two decades. Is expected that environmental compliance with the Forest Code increase the forest coverage (A. A. Azevedo et al. 2017; Soares-Filho et al. 2014; Costa et al. 2018; Federal Law 12.651 2012).

Similarly, scholars pointed out that deforestation is lower in areas with higher secure land tenure. Forest clearing often becomes a way to claim property rights to land. (Angelsen 1999; Costa et al. 2018). The Brazilian government dictated for all rural properties to register their georeferenced limits at INCRA, and in blacklisted municipalities landowners that refuse to comply had their property registration certificate revoked blocked their access to credit. This georeferenced certification aims to reduce conflicts of demarcation, the falsification of titles, and land grabbing, creating an environmental liability for registered farmers. Via satellite monitoring, environmental infractions (deforestation or lacking forest restoration) can be traced to specific farms. The risk of detection increases significantly and the profitability of new forest clearings on registered land reduces. Secondly, registration and compliance with environmental regulations reopens the opportunity to access public credit, reducing the deforestation.

Productivity gains for sustainable production are also expected to lead to deforestation reductions. New investments in sustainable agricultural activities become possible and more profitable. The support for new forest friendly agricultural systems (e.g. honey production) and the strategy to intensify cattle production increases the profits per hectare of land. Without a sufficient level of environmental monitoring and enforcement, the additional profits could lead to an increase in the demand for land and thereby increase forest losses. On the other hand, the increased municipal monitoring activity and the increased environmental liability of farmers due to the geo-referenced registrations limits land use decisions and the additional profitability per hectare land can result in land sparing.

Finally, social cohesion is seen as a key ingredient in reducing deforestation rates. The project coordinated the collaboration of various stakeholders collectively facing negative economic effects. Politicians, farmers, ranchers, scholars, non-governmental organizations private companies organized jointly to remove Alta Floresta from the blacklist. The collective benefit of exiting the blacklist stood in contrast to the individual disadvantage of complying with environmental regulations. Registering in an official geo-referenced cadaster limits farmer land use decision and reveals your environmental compliance status. The individual negative economic consequences from geo-referencing and reducing forest clearings could be only reduced if all farmers registered simultaneously. A joint registration of all farmers could reduce the expected risk of environmental law enforcement to each farmer as well as the decrease the losses from a shift to forest friendly land uses. The project may have managed to overcome the collective dilemma and motivate targeted and non-targeted land holders to register. In consequence, to project may have produced positive spillovers by inducing a behavioral change across the municipality, which reduced deforestation rates sustainably.

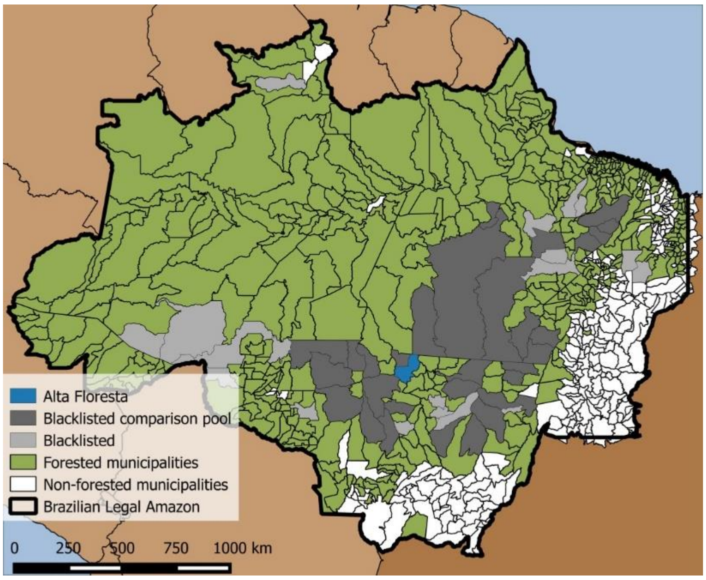
3. Synthetic Control Method

Given that most conservation interventions including this one were not done via randomization, in an experimental approach, quasi-experimental methods thatt attempt ‘apples to apples’ comparison have increasingly been used to evaluate environmental conservation policies and projects (CEPAL and others 2011; Assunção, Gandour, and Rocha 2012; Hargrave and Kis-Katos 2013; Arima et al. 2014b; Nolte et al. 2013; Soares-Filho et al. 2010; Börner et al. 2015). Most such methods rely on large samples from several treated units, compared to many untreated, to assess a causal relationship between an interventions and outcomes. Since the project Olhos d'Água da Amazônia was implemented in only one municipality, we employ a statistical analog to case comparison, which focuses on finding other cases to match well with the treated unit's past.

Specifically, we employ the Synthetic Control Method SCM, from Abadie and Gardeazabal (Abadie and Gardeazabal 2003), a generalization of differences-in-differences (DID) approaches to compare time changes over units. SCM uses a data-driven approach to find the comparison group by searching for a weighted blend of comparison units that best match the trajectory of the outcome for the treated unit pre-treatment. (Abadie and Gardeazabal 2003; Abadie, Diamond, and Hainmueller 2010). Then the post-treatment trajectory of the outcome for the treated unit is compared to the post-treatment trajectory of that same weighted blend of the outcomes for those comparison units.

Before searching for that weighted blend, we must judge which municipalities share characteristics with Alta Floresta, such that they would be good candidates to put in the pool of possible units for comparison. Given the history of deforestation in the Brazilian Amazon (summarized in Figure 1), the characteristic of having been blacklisted seemed to be one critical commonality to insist upon. As noted above, in 2008 Alta Floresta was included in the blacklist of 36 municipalities (Figure 3) exposed to a suite of federal environmental conservation restrictions and interventions (Arima et al. 2014b; Cisneros, Zhou, and Börner 2015).

Figure. 3 Alta Floresta and blacklisted municipalities in 2008



As we want to isolate any effect of the Olhos d'Água project, we include other blacklisted municipalities in our comparison pool – from which the statistical method picks a 'best matching' weighted blend. This choice is particularly appropriate for the deforestation outcome and the related registrations. Since concerning the latter, only the states of Mato Grosso and Pará had the CAR in operation at the time of our intervention, we further restricted our comparison pool to those two states, yielding 30 such potential comparison municipalities. Finally, because Paragominas municipality in Pará went off the blacklist in 2010 while Alta Floresta started in 2011, we dropped it, yielding 29 totals.

Using those 29 potential comparison units, the SCM approach generates weights (W) for each unit – many of which are zero, i.e., the blend is often of only a few − to constructs a synthetic control. Once that linear combination of the selected units' outcomes is created, we must evaluate the quality of the match, i.e., whether the best possible fit as assessed by the SCM actually fit well or poorly. Given an excellent fit, we can then estimate the impact of the treatment by comparing outcomes post-treatment between Alta Floresta and the weighted blend. Given a reasonable fit, we cannot make the same strength of claims but likely could bound the impacts. Yet the fit can be quite poor.

Finally, with any such impact estimate in hand, it is necessary to assess its statistical significance. (Abadie, Diamond, and Hainmueller 2010) recommend placebo tests (Abadie, Diamond, and Hainmueller 2010), i.e., pretending each municipality in the comparison is treated and estimating an impact where none should exist, in order to characterize the 'noise' in the SCM's approach. Any significant impact estimate must stand out over these placebo effects. In addition, Sills et al. (2015) recommend a bootstrapping method to construct confidence intervals around the synthetic control trend. For 1,000 rounds we randomly exclude units form the pool of synthetic controls (Sills et al. 2015). Both methods show similar result, and we therefore present only results of the bootstrapping method and display the placebo tests in the appendix.

Given that most uses of SCM in this field are quite recent, we might spell out the details of this process a bit further. As noted, the synthetic control approach considers both: characteristics of any municipality and its past outcomes. Both should be very similar for the weighted blend of controls, which is literally constructed as a linear combination: X% of potential comparison municipality A; Y% of potential comparison municipality B; Z% of potential comparison municipality C, and so on.

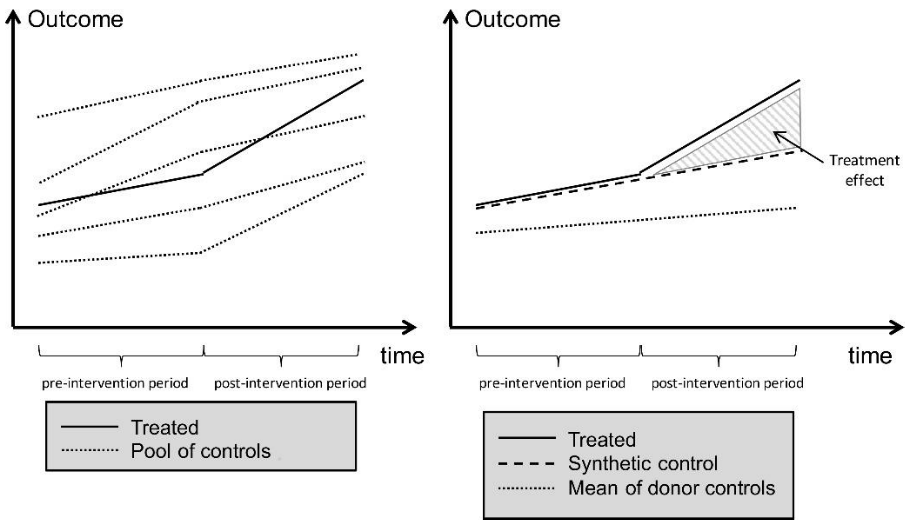
Weights are chosen in two steps to minimize the distance between the values of the covariates and the past outcomes for the synthetic control, or weighted blend, and the treated unit. In a first step, to avoid excessive influence of covariates, they are weighted by their predictive power for the outcome. In the second step, the quality of the synthetic control unit is adjusted for ‘closeness’ of its outcome to those of the treated unit. The measurement used is the mean squared prediction error (MSPE):

$$(Y_1 - Y_0W^*)'(Y_1 - Y_0W^*)$$

where Y_1 is the vector of outcomes of the treated unit in the pre-intervention period, Y_0 is the matrix of outcomes of all untreated (control group) in the pre-intervention period, and W^* is the optimal weights vector giving the single weights to each untreated unit from the control group. To evaluate the fit, we will focus prior to the intervention but after the blacklisting policy, between 2008 and 2010. Abadie et al. (Abadie, Diamond, and Hainmueller 2010) shows that with a good fit in pre-treatment outcomes, the SCM is a generalization of differences-in-differences thinking and can provide a mean treatment effect on the treated (Abadie, Diamond, and Hainmueller 2010).

Figure 4 helps to illustrate this approach. The search is for a good weighted blend synthetic control, i.e., a good fit in the pre-intervention period as in Figure 4, where the selection of the comparisons (left panel) yields a great match to the past outcomes for the treated unit (right panel), different from the mean of the pool. Then impacts are calculated as the differences between the treated and synthetic control outcomes, with one estimate per unit of time, i.e., Figure 4’s shaded triangle for the post-intervention period.

Figure. 4 The Synthetic Control Method



Adapted from Pfeil and Feld (Pfeil and Feld 2016)

4. Data

Our two main outcome variables are deforestation and the geo-spatial registries at the rural environmental cadaster (CAR) and at the National Institute for Colonization and Agrarian Reform (INCRA). Forest loss data is from the INPE PRODES system (Prodes 2017) and measured as the newly clear cut deforested area in each year. CAR registry data were obtained from the secretaries of environment of the states in collaboration with the Institute of Environmental Research of the Amazon (IPAM), through 2012. The records indicate areas in polygons, permitting calculation of CAR area relative to area of the municipality. The latter was defined excluding protected areas – both strict and sustainable use − and indigenous territories. The outcome we consider is the annual percentage increase in CAR coverage. This is consistently below official statistics due to protected areas being only those prior to 2003 and that the farm polygons in the CAR database often overlap or are registered more than once (Figure 37). Georeferenced INCRA records were obtained from INCRA (INCRA 2017). The SNCI (National System of Properties Certifications) was the main database until 2013. In late 2013, INCRA adopted the SIGEF (Land Management System), which made it easier for authorized engineers to do registrations without going to INCRA headquarters, with remote analysis and approval by INCRA. The systems coexisted for some time but no significate overlaps were noted between these two databases.

We furthermore test for effects on aggregate outcomes of supported agricultural production lines. We use official statistics on honey and milk production. Honey production data is obtained from IBGE Livestock Research and measured in Kilograms Annual milk production is also from IBGE and measured in Liters (IBGE 2017).

As covariates to construct the synthetic control, we use pre-treatment outcomes as well as pre-treatment socio-economic and bio-physical characteristics. Demographic data is collected from IBGE and the Brazilian Central Bank. Administrative and geophysical data is collected from EMBRAPA, IMAZON and IBGE. We include the yearly number of inspections from IBAMA. Furthermore, we use mean distance of each municipality from river lines (from the National Water Agency), mean distance of each municipality to the vicinal roads (from IMAZON), mean distance of municipality headquarters. As geophysical and geological characteristics we include soil quality from EMBRAPA, agriculture suitability from IBGE, and slope and terrain characteristics from CSR/UFMG.

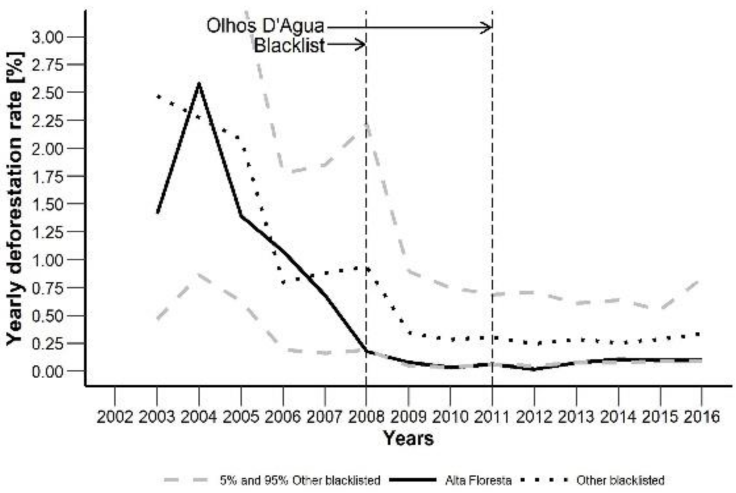
5. Results

We evaluate the effects of Olhos D'Água via multiple channels. First, we assess it impact on environmental performance, i.e. on yearly deforestation rates after treatment. Second, we use the yearly data on geo-referenced registrations to assess its effect on overall registrations. Finally, we analyze the sustainable production channels which were supported by the project, i.e. honey and milk production. Our assessment is restricted due to the narrow timeframe and the limited area targeted. The program was implemented in 2011, which gives only two to six years of observations post treatment. The short time of the impact possibly downward biases our results. Furthermore, the project targeted only a few farms. The project targeted small land holdings and agricultural support was provided to a small number of farms. Our empirical methodology uses aggregate data at the municipality level, therefore we cannot distinguish between the direct effect on the targeted farmers and the effect of the project on non-targeted farms. Nonetheless, this spillover effect was intended by Olhos D'Água as it aimed to change the municipalities environmental governance of all stakeholders. For all synthetic control estimates we report the covariate weights, the optimal blend of control municipalities, and the placebo analyses in the appendix.

5.1 Environmental compliance

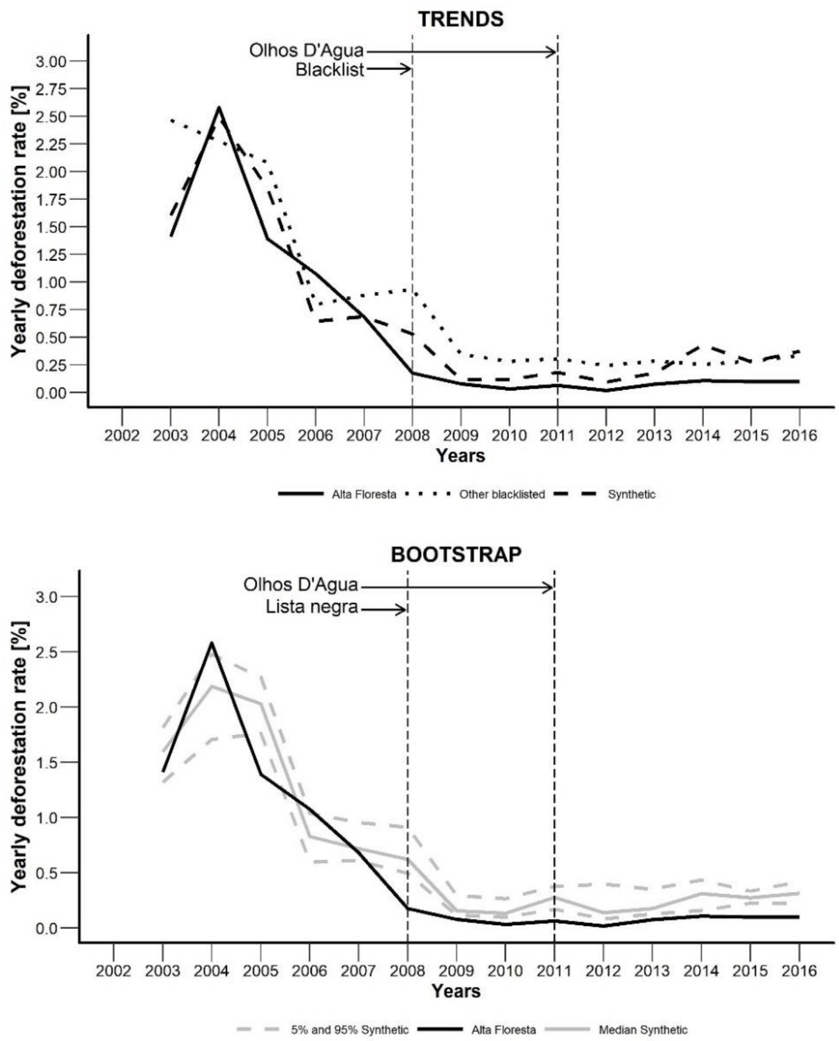
Figure 6 present the results of the impact assessment of the Olhos D'Água project on yearly forest losses. Before using the synthetic control method, we plot deforestation tends of Alta Floresta and the pool of controls in Figure 5. It becomes evident, that deforestation rates dropped sharply in 2008 when the municipality was blacklisted. After 2008, deforestation rates are below the mean of all other blacklisted districts and align with the trend of the 5th percentile of the distribution. Being at the lower edge of the distribution, limits the possibility to find a good blend of controls that could resemble the deforestation path of Alta Floresta between 2008 and 2010.

Figure. 5 Deforestation trends of Alta Floresta and the blacklisted controls



The result of the synthetic control is depicted in Figure 5. As expected, the synthetic control is unable to simulate the trend line of Alta Floresta in years before treatment. Deviations seem visually low, but tests on the mean prediction error reveal the low quality of the synthetic control (see Figures 12, 13 and 14 in the appendix). After bootstrapping the 90% confidence interval shows that deforestation rates of the synthetic control are significantly higher before treatment, in years 2008 to 2010 and therefore also significantly higher in years after treatment.

Figure. 6 Deforestation trends of AF and the Synthetic AF and Bootstrapped significance to Synthetic AF

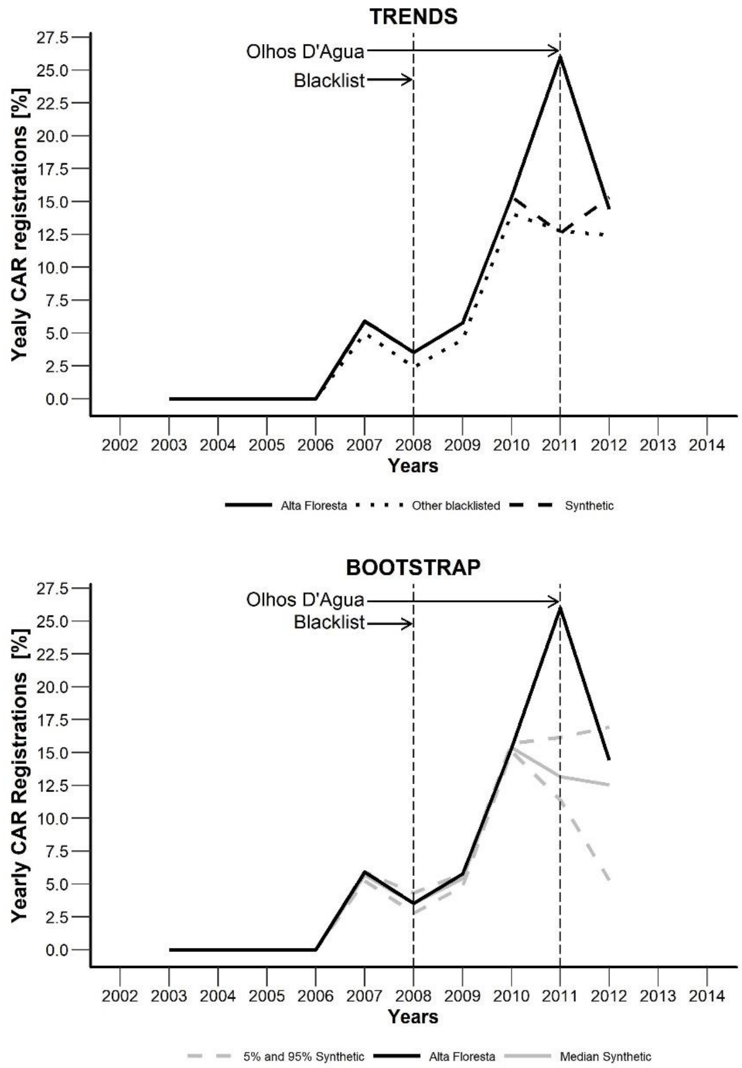


Hence, deforestation rates in Alta Floresta differed from the dynamics in the comparison group already before the Olhos D'Água project began (Figure 6 upper panel). Deforestation rates, nonetheless, stayed remarkably low in Alta Floresta since project start and have remained so ever since. Our findings (including based on bootstrapped confidence intervals in Figure 6 lower panel are not conclusive as to whether this is a result of Olhos D'Água project or simply reflects the general trend of forest loss in comparable municipalities. It is worth to note, that the difficulty to find a good control cannot be interpreted as a missing effect of the project on deforestation rates.

5.2 Environmental Registrations

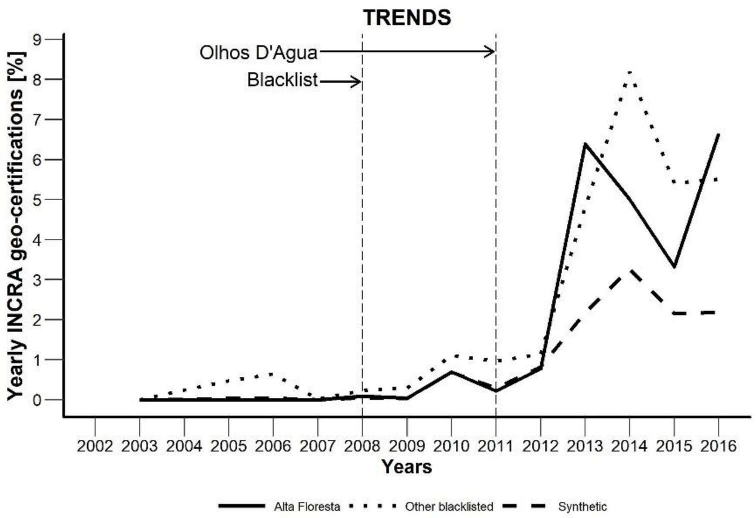
The Olhos D'Água reported that carried out 2.040 CAR projects (composed by the geo-referencing plus the required documentation) attending 2.801 properties at the rural environmental cadaster (CAR) during the first phase and 400 projects were rectified to enable the migration to the National CAR during the second phase. In addition, Olhos D'Água geo-referenced 1.220 perimeters but only 93 projects were sent to be certified by INCRA, justified by the strike between May and September 2012 and the necessity to travel 800 km to the headquarters of INCRA to register in the former SNCI certification system. An additional 530 perimeters were geo-referenced during the second phase, and despite the new certification system, SIGEF, which made it easier for authorized engineers to do registrations without going to INCRA headquarters, not were reported by Olhos D'Água the quantity of projects sent to be certified by INCRA. Our empirical evaluation aims to estimate how many registries would have happened without the intervention for both phases. Figure 8 shows the yearly new CAR registries as the percentage share of the municipality area. Official registrations started to rise in 2007 and continuously increased until 2011 with more than 25% of the land registered in one year. All other blacklisted municipalities show identical increases until 2010, but afterwards remain at an average around 14% of newly registered land in each year. Comparing the synthetic control to the trend in Alta Floresta shows a very good fit in pre-treatment years, supported by tests on the mean prediction error (see Figures 15, 16 and 17 in the appendix). Only the 2011 pike in registries is unprecedented and around 13.6 percent higher than the synthetic control. The effect is large and significant. The bootstrapping (Figure 7) excessive shows that the path of the synthetic control is not significantly different from Alta Floresta in pre-treatment years, but significantly lower at a 10% level in 2011.

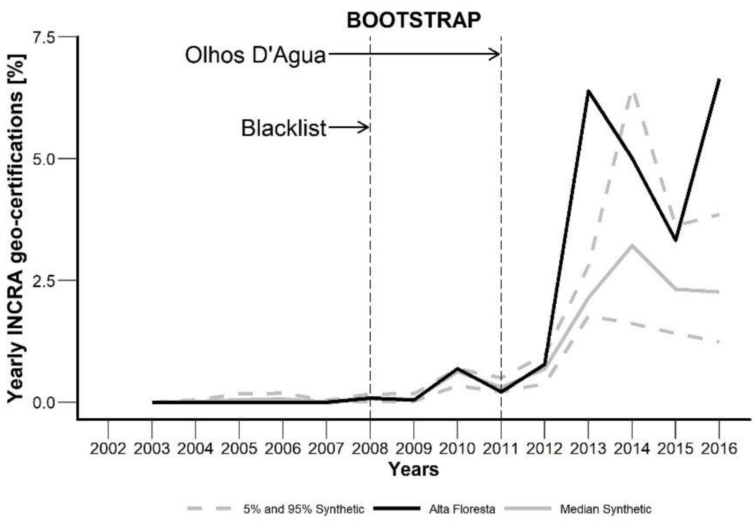
Figure. 7 CAR trends of AF and the Synthetic AF and Bootstrapped significance to Synthetic AF



The effect on geo-referenced registrations with INCRA is less pronounced. Figure 8 upper panel shows again the trend lines of the Alta Floresta and the other blacklisted municipalities. All municipalities experience a sharp increase, though Alta Floresta seems to experience its high with a one-year lead in 2013. The confidence intervals of the bootstrapping methodology (Figure 8 lower panel) confirm, that the synthetic control is fitting well the Alta Floresta trend in pre-treatment years, analysis also supported by tests on the mean prediction error (see Figures 18, 19, 20 and 21 in the appendix). Registries are consistently higher in Alta Floresta after 2012 compared to the synthetic control. A significant difference can be detected in 2013 and 2016 with a 4.21 and 4.46 percent higher rates of registered land. Two points are worth noting: First the effect seems to lag one year behind, starting only in 2012. This peak may be partially explained by the employee strike at INCRA between May and September 2012, therefore the acceptance of the cases was delayed. Besides this fact, at this time INCRA was working with the former system SNCI, requiring the physical presence of the applicants at its headquarters. Second, the effect seems only to hold for the year 2013. All other blacklisted municipalities seem to be cashing up within the following years. This delay can be explained by the decree which determine that all properties over 250 ha must be certified on INCRA until December 2013, and with the support of the project the Alta Floresta farm owners advanced in this certification, cashed up by the others blacklist municipalities within the following years. The same movement can be noted in 2016 where all properties over 100 ha must be certified on INCRA until December 2016.

Figure. 8 INCRA trends of AF and the Synthetic AF and Bootstrapped significance to Synthetic AF





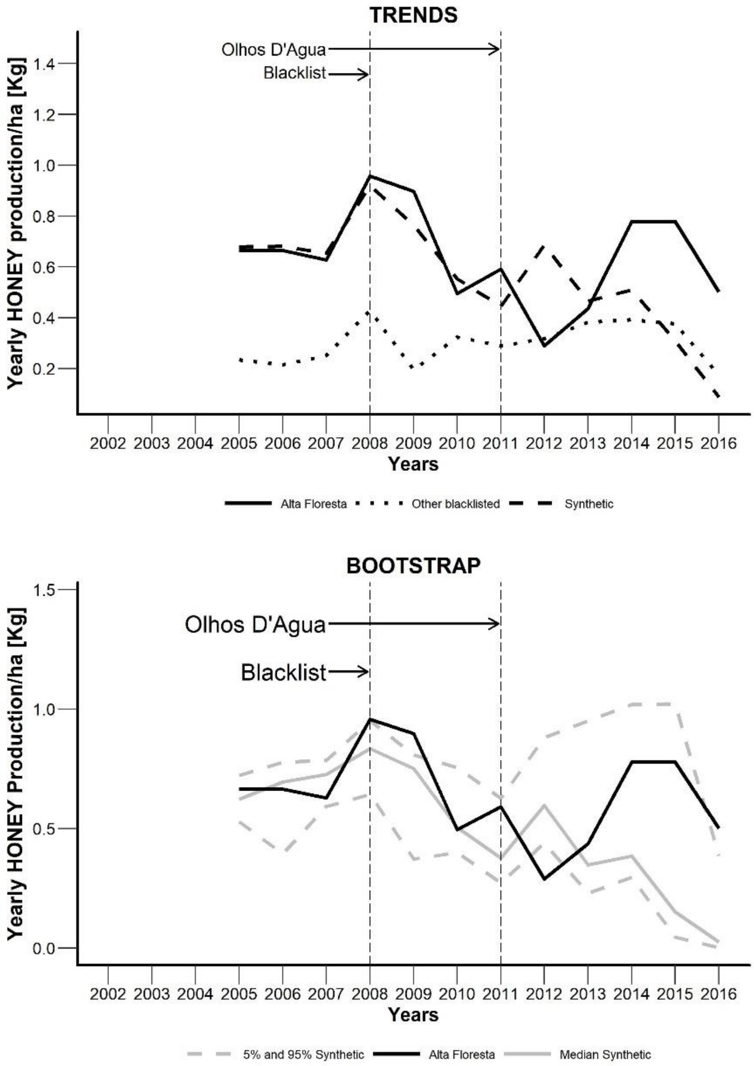
5.3 Production Support

The project Olhos D'Água provided training and material support to develop forest friendly agricultural systems. We test the effect of the program on honey and milk production.

The second phase of the project supported the consolidation of the municipality honey production plant with 300 beehives matrices, beyond the acquisition or internal production of additional beehives to be transferred to farm owners interested in establishing honey production that voluntarily enroll at capacitation courses and that the property is registered in CAR. The Olhos D'Água reported 64 farm owners that received the matrices and the donation of 381 beehives to them start the honey production. After the end of the 2nd phase of Olhos D'Água, this plant is still active and several beehives has been donated to municipalities schools and farmers.

Figure 9 upper panel presents the synthetic control analysis using as the first outcome kilogram of honey production normalized by the municipality areas. Production levels of honey fluctuated during our timeframe and a trend is not recognizable. The synthetic control fits the trend line of Alta Floresta reasonably well in pre-treatment years (2008-2010) and the bootstrapping method shows no statistical difference between the trend lines before treatment, with a small exception in 2009 (Figure 9 lower panel). Post-treatment, production in the synthetic control is first higher but falls below Alta Floresta in 2014 onwards. Bootstrapping does not show a consistent significance at the 10% level after treatment. Nonetheless production is consistently lower after 2013 in the synthetic control. Figures 25, 26 and 27 in the appendix show the placebo estimates, and 18 remaining placebos have at least as good fits as the Synthetic control of Alta Floresta.

Figure. 9 HONEY trends of AF and the Synthetic AF and Bootstrapped significance to Synth AF



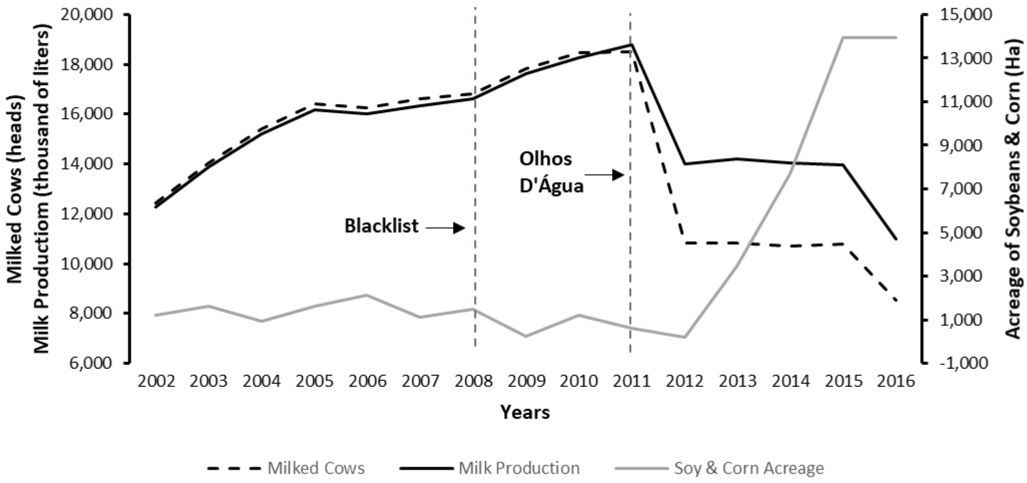
Yet, the differences after treatment are larger than that, first downward and then trending upward and staying above controls. The placebo estimates further suggests a small ongoing impact after 2013. Only one out of the 18 simulations have a positive and higher production gap between synthetic control and treatment after 2013. This is consistent with the increased focus on honey production during the second Phase. Therefore both methods suggest moderate causal effects on honey production towards the end of the second phase of the project exist.

Figure 10 depict the growing up trend of milk production in Alta Floresta up to 2011 highly correlated with the quantity of milked cows, presenting a peak of 18,500 heads and 18,802 thousand liters produced, and after 2011 the trend collapses up to 2016. In parallel the area under for soybeans and corn production sharply increased from around 8000 to 14000 hectares. Regarding the low deforestation rates during this period (3260 hectare from 2011 to

2015), it suggests a replacement between these activities. One point is worth noting: The timing of the decoupling between the milk production and the quantity of heads milked could suggest an impact of the Olhos D`Água project on the growth of productivity of milk production.

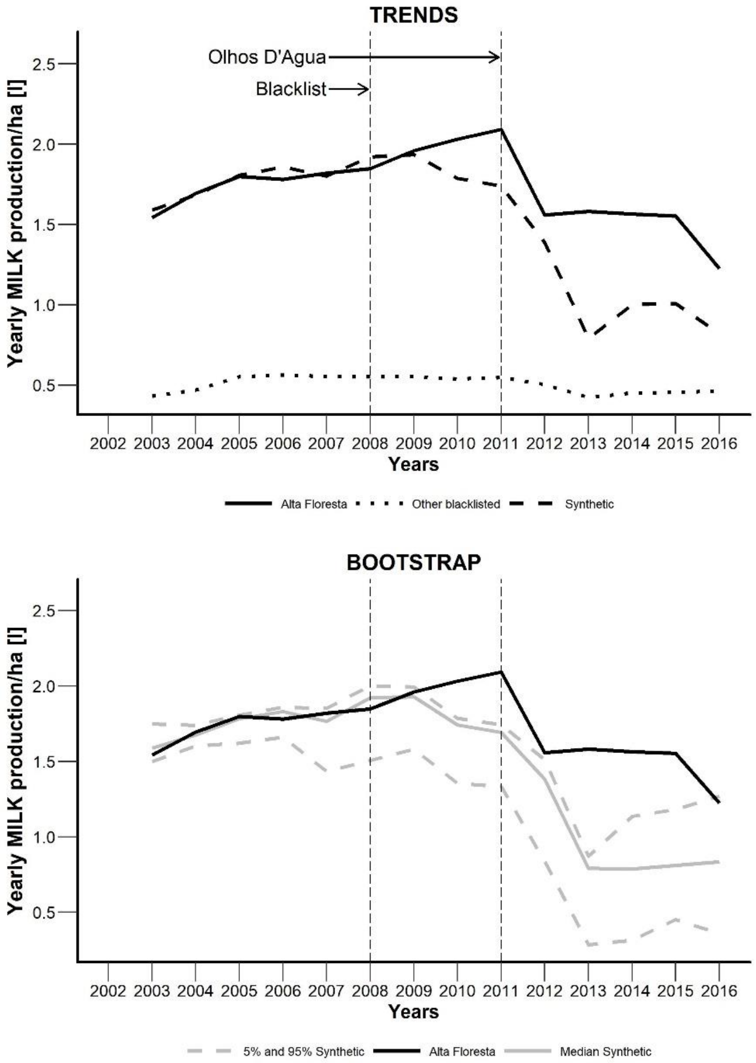
Figure. 10 Milked Cows, Milk Production and Acreage of Soybeans & Corn of Alta Floresta

Source: (IBGE 2017)



Our empirical evaluation aims to estimate how much lower would be the production of milk without the intervention of the project. Testing the hypothesis that direct support could increase milk production, we next evaluate that possible project impact. Figure 11 upper panel shows that the productivity of milk per hectare land is three to four times higher in Alta Floresta then in other blacklisted districts. is also quite illustrative − and of both support and challenges for this approach. Once again, the fit is very good before the blacklist and we highlight that the fit is at a level very different from the average over all possible comparison municipalities. Thus, the selection done by the SCM really is managing to put weight on units more similar to Alta Floresta. However, at the point of blacklist until the treatment, the fit is not perfect. Thus, it seems other blacklisted municipalities fell more in milk productivity after being blacklisted. This greatly affects one’s interpretation of treated-versus-controls differences after the treatment. One could simply judge the match to be poor. Alternatively, if the differences become larger than the difference at the point of treatment, this could be suggestive of an impact even if less precise. Along those lines, Figure 11 lower panel, which shows just the differences between the synthetic control blend and Alta Floresta, suggests positive (then perhaps falling) impacts on milk productivity from 2013.

Figure. 11 Milk – Alta Floresta trends and the Synthetic (left) and Bootstrapped significance to Synthetic (right)



Tests on the mean prediction error reveal the low quality of the synthetic control (see Figures 22, 23 and 24 in the appendix), manly affected by alterations after the blacklist policy. Bootstrapping shows a consistent significance at the 10% level only up to 2009, 2 years before the treatment. Still these figures are consistent with, as for honey, some positive impact in later years though still just at the edge of significance.

6. Conclusion

It is possible to conclude that the project "Olhos D'Água da Amazônia" played an important role in the effort of Alta Floresta to have the municipality removed from the blacklist of deforestation at least, in a shorter period than would be in the absence of the project. Strong evidence for this can be seen in the increase of CAR registration above the general trend observed in the control group. Strong evidence is also verified in the growth of the INCRA geo-certification records upper the general trend observed in the control group, despite Alta Floresta be composed widely by properties under 250 ha and this register be required just after Dec. 2016. The recovery of degraded of Permanent Protected Areas as sources and river slopes, one important outcome aimed and supported by the 2 phases of Olhos D'Água da Amazônia project was not evaluated by this study.

Many of these areas were registered in CAR and geo-certified in INCRA with funds from the Amazon Fund-supported project, but it is possible to assume that this effect includes not only the small properties that entered the system, but also the untreated neighbors, since they are indirectly motivated to register due to project intervention. In addition, the support from the municipality secretariats of environment in command and control activities, enforcing the application of the environmental laws, may also have led to an increase in the voluntary registration of farms without a direct intervention (Costa et al. 2018). Likewise, it there is evidence that the project has affected positively the milk and the honey production, even though we did not find sufficient inferences in this study to indicate direct a relation cause effect. In sum, the project not only achieved its stated objectives but there is evidence that those results would not have happened in the absence of the support from the Amazon Fund.

According to the theory of change behind Olhos D'Água, it should be expected that improvements in land tenure, environmental governance and agricultural production intensification would lead to reductions in deforestation. However, it was not possible to observe a significant reduction in forest loss in comparison to the synthetic control. While the results were not significant, it cannot be said that the project had a positive or a negative effect on deforestation rates, it was expected a much clearer effect in terms of deforestation reduction.

It is also necessary to recognize that there is space to achieve even more substantial results in the reduction of deforestation from the investments in the CAR carried out by the project Olhos D'Água da Amazônia. As indicated by (Rajão, Azevedo, and Stabile (2012) and (A. Azevedo et al. (2014), little effectiveness was obtained in pattern deforestation reductions, either with the SLAPR between 2000-2008 or with the CAR in the 2008-2012. It was observed by the authors that this low effectiveness stems from the fact that both federal agencies such as the Brazilian Environmental Institute (IBAMA) and the state and SEMA (Secretariats of the Environment) have not used these systems as an instrument of command and control through of the automatic issuance of notifications and notices of infraction from deforestation or degradation detected by satellites or by the not fulfillment of the terms of restoration committed by the dweller when they adopted the geo-referenced registers.. This can be explained by the adoption of a strategy that sought to priority of registration campaigns in these systems to the detriment of their use for the control of deforestation through punitive actions that could dissuade the producers to seek registration in the CAR. At the same time, concrete economic incentives are lacking for the reduction of deforestation within the properties and for the restoration of permanent protection areas and legal reserve. This indicates that in the future the governance infrastructure set up by the Amazonian Olhos d'Água project could be mobilized towards a substantial improvement in the municipality's environmental governance and the achievement of zero illegal deforestation in the region.

While Olhos d'Água did not deliver the expected results in terms of deforestation reduction during the period 2011-2016, it should be highlighted that the results obtained by the project may lead to an impact only on the long term. This suggests that while impact analysis such as the one proposed in this study should be considered an ongoing process rather than a static evaluation of the status quo. It also indicates the need to continuously seek in the management of jurisdictional REDD+ projects as well as other types climate initiatives, not only the achievement of specific pre-defined results but also a long-term impact on the reduction of greenhouse gases.

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Supplements

Figure. 12 Deforestation GAP between Alta Floresta and Synthetic Control

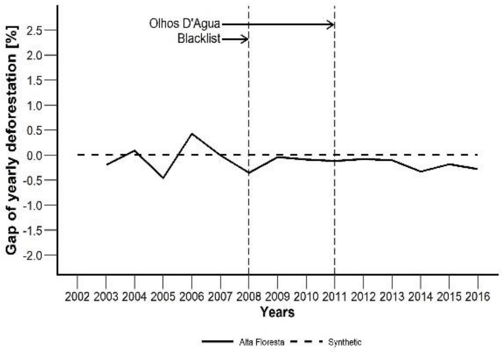


Figure. 13 Placebo Deforestation gaps in all 29 control group municipalities and their respective synthetic control

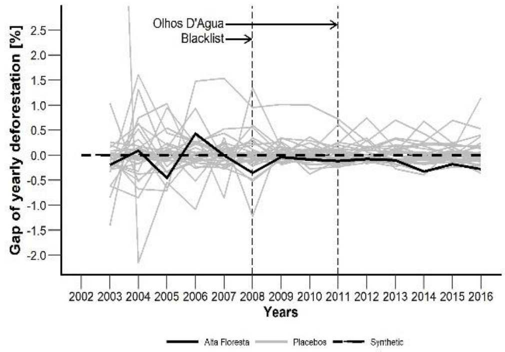


Figure. 14 Placebo Deforestation gaps in 16 control group municipalities (discarded municipalities with pre-intervention MSPE higher than Alta Floresta) and their respective synthetic control

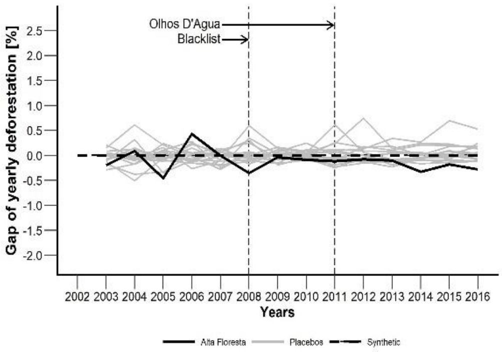


Figure. 15 CAR Registrations GAP between Alta Floresta and Synthetic Control

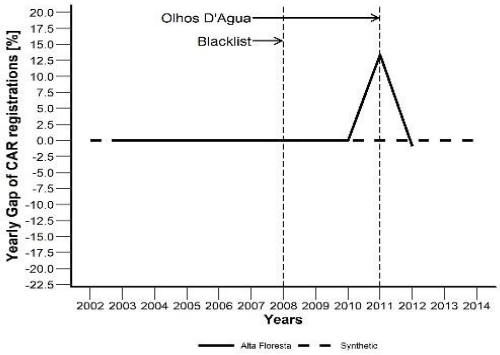


Figure. 16 Placebo CAR registrations gaps in all 29 control group municipalities and their respective synthetic control

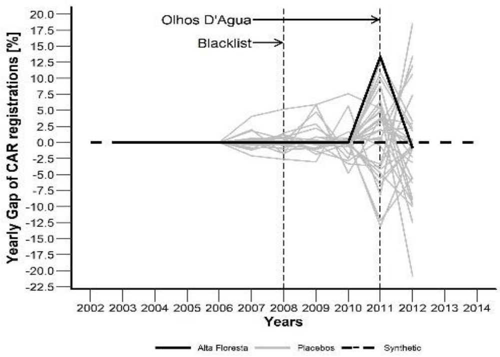


Figure. 17 Placebo CAR registrations gaps in 8 control group (discarded municipalities with pre-intervention MSPE 300 times higher than Alta Floresta) and their respective synthetic control

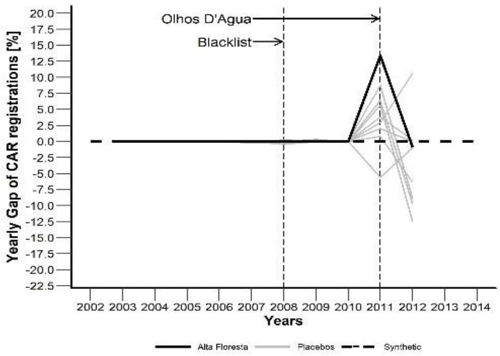


Figure. 18 INCRA geo-certification GAP between Alta Floresta and Synthetic Control

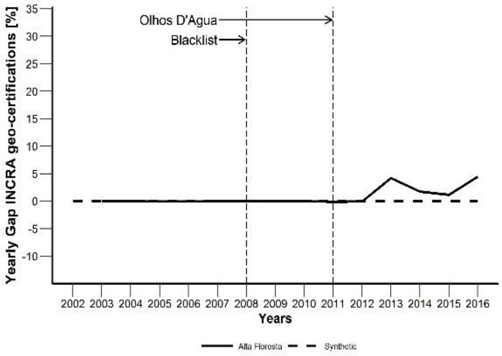


Figure. 19 Placebo INCRA geo-certification gaps in all 29 control group municipalities and their respective synthetic control

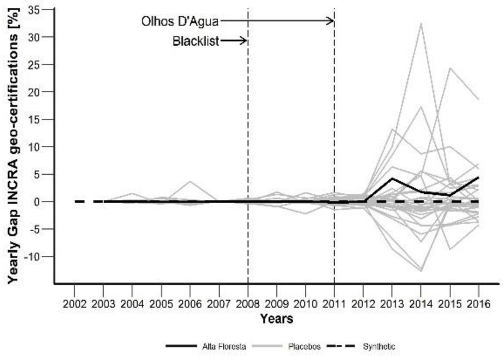


Figure. 20 Placebo INCRA geo-certification gaps in 19 control group (discarded municipalities with pre-intervention MSPE 40 times higher than Alta Floresta) and their respective synthetic control

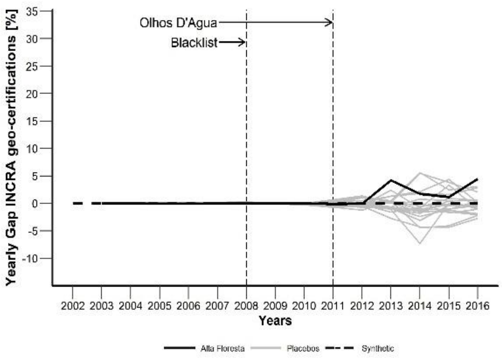


Figure. 21 Placebo INCRA geo-certification gaps in 10 control group (discarded municipalities with pre-intervention MSPE 2 times higher than Alta Floresta) and their respective synthetic control

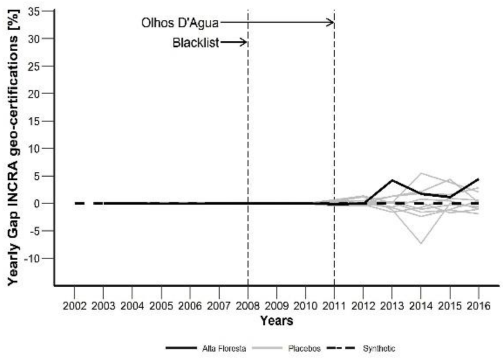


Figure. 22 Milk Production GAP between Alta Floresta and Synthetic Control

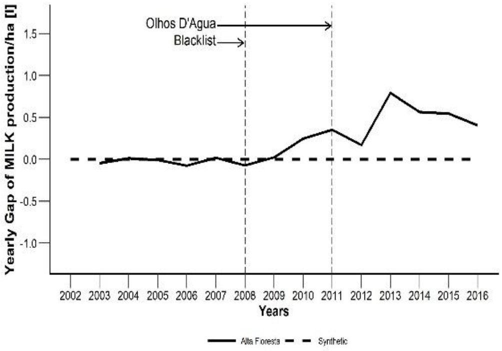


Figure. 23 Placebo Milk Production gaps in all 29 control group municipalities and their respective synthetic control

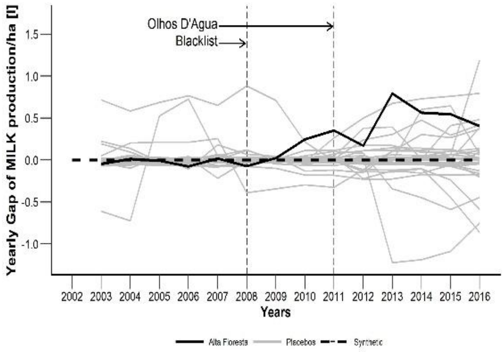


Figure. 24 Placebo Milk Production gaps in 24 control group (discarded municipalities with pre-intervention MSPE higher than Alta Floresta) and their respective synthetic control

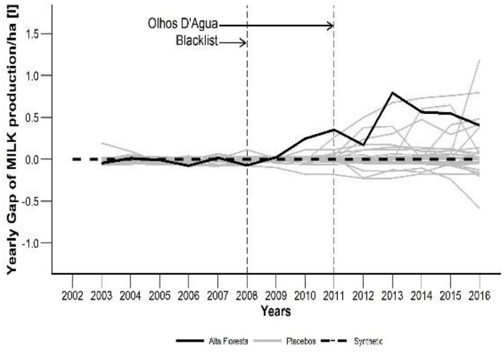


Figure. 25 Honey Production GAP between Alta Floresta and Synthetic Control

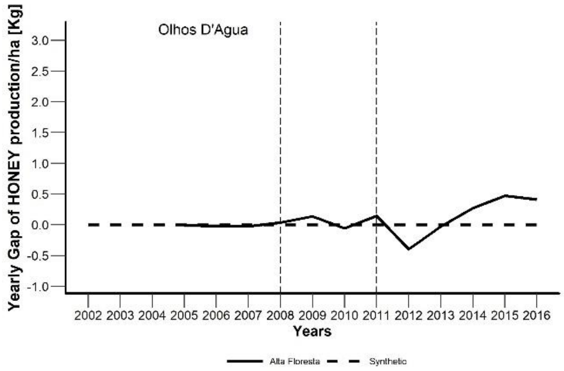


Figure. 26 Placebo Honey Production gaps in all 29 control group municipalities and their respective synthetic control (any discarded municipality from control group)

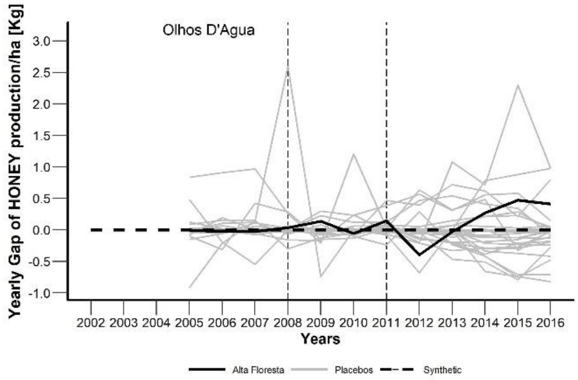
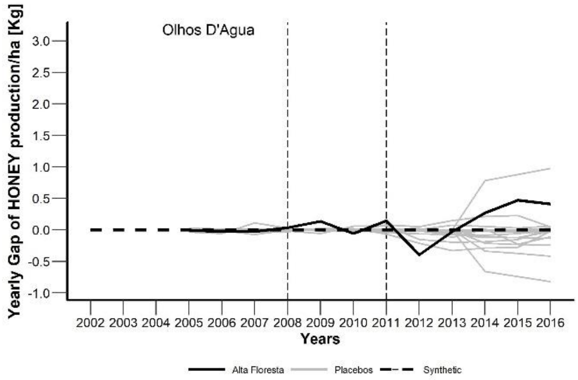


Figure. 27 Placebo Honey Production gaps in 18 control group (discarded municipalities with pre-intervention MSPE higher than Alta Floresta) and their respective synthetic control



Data

The period of this analysis includes data from the municipalities of the Amazon from 2002 to 2016. The registry data in the CAR were obtained from the secretaries of environment of the states in collaboration with the Institute of Environmental Research of the Amazon (IPAM), and only include data up to 2012. The records in the CAR were measured as areas covered by spatial polygons, and through this means the proportion of area recorded in the CAR in relation to the area of the eligible municipalities was calculated (see Figure 28). The eligible area was defined as the area of municipalities excluding protected areas (protected areas for sustainable use and full protection) and indigenous territories. The outcome variable is defined as the annual percentage increase in CAR coverage in municipalities.

Figure. 28 Deforestation in Alta Floresta

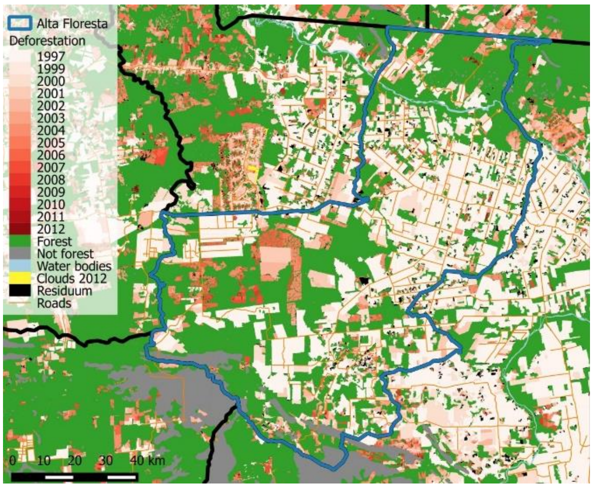


Figure. 29 CAR registered in Alta Floresta

Forest cover data and annual deforestation rates were obtained through the INPE PRODES system (Prodes 2017) (See Figure 29).

This percentage measurement is consistently below official statistics due to two technical factors: First, the baseline was built in protected areas established prior to 2003. Secondly, farm polygons in the CAR database often overlap or are registered more than once. PostgreSQL database with the spatial extension PostGIS was used to only account registered areas once (see Figure 28 and 29).

The georeferenced INCRA records base were obtained through the INCRA. The National System of Properties Certifications - SNCI from the acronyms in Portuguese, was the main database to georeferenced certifications up to 2013. At Dec 2013 INCRA adopted the Land Management System SIGEF, from the acronyms in Portuguese. The SIGEF made it easier the geo-certifications enabling authorized engineers made the register without move to the INCRA headquarters, the records should just be analyzed and approved remotely by INCRA. Both System coexist for few times. No significative overlaps were noted between the two databases shapefiles, see Figure 30 and 31.

Figure. 31 SNCI geo-certification in

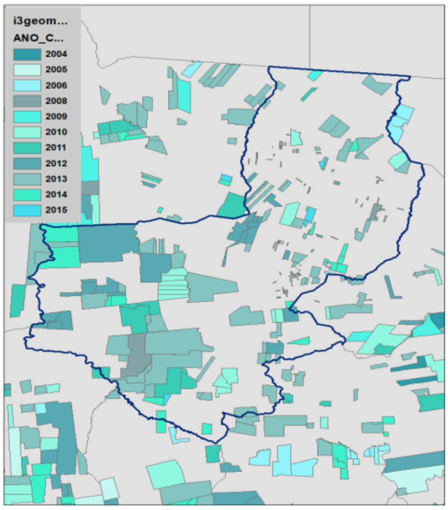
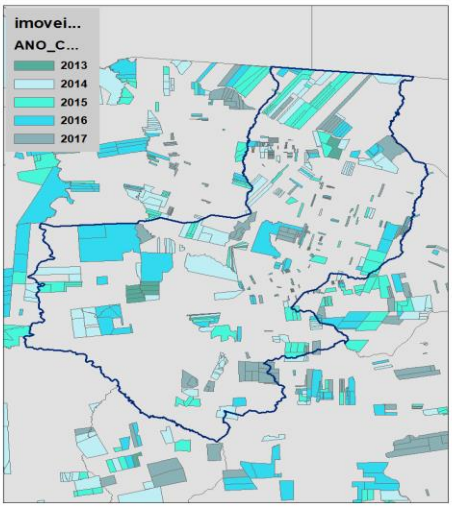


Figure. 30 SIGEF geo-certification in



Calculated Covariates

For the covariates used to build the synthetic control (Figure 32), beyond socioeconomic and demographic data collected from IBGE and Brazilian Central Bank, administrative and geophysical data collected from EMBRAPA, IMAZON and IBGE, inspections and environmental data from INPE and IBAMA and the cited INCRA e CAR records, few covariables historically correlated with deforestation were calculated: mean distance of each municipality of the river lines from the National Water Agency, mean distance of each municipality to the vicinal roads from the NGO IMAZON, mean distance of municipality headquarters, and also which include geophysical and geological characteristics like soil quality from EMBRAPA, agriculture suitability from IBGE, slope and terrain suitable to mechanized agriculture from CSR/UFMG.

Figure. 32 Calculated Covariates for Pará and Mato Grosso

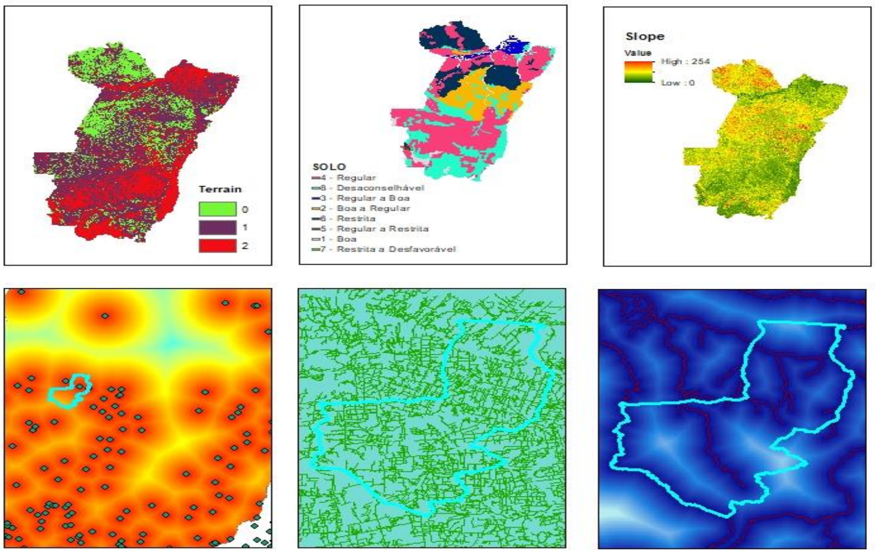


Table 1 Data Source

Variable	Year(s)	Source
Blacklist additions and removals	2008-2016	Decree 6.321/2007 and Provision 28/2008, Provision 102/2009, Provision 67/2010, Provision 138/2011, Provision 139/2011, Provision 175/2011, Provision 187/2012, Provision 323/2012, Provision 324/2012, Provision 412/2013
Deforestation	2002-2016	INPE-PRODES
Municipality list and borders	2015	IBGE
Protected areas	2002-2016	IBAMA
Indigenous areas	2002-2016	IBAMA
Rural credit	2002-2016	BCB
GDP (lagged)	2002-2016	IBGE
Field-based law enforcement inspections (lagged)	2001-2016	IBAMA
Farm density (per km^2)	2006	IBGE Agricultural Census
Share of small farms	2006	IBGE Agricultural Census
Share of land owners	2006	IBGE Agricultural Census
Number of tractors per farm	2006	IBGE Agricultural Census
Cattle stocking rate	2006	IBGE Agricultural Census
Population density	2007	IBGE Demographic Census
Mean distance to municipalities headquarters	2015	Own calculation over IBGE municipalities points localizations
Mean distance to Rivers	2015	Own calculation over ANA river lines
Mean distance to Roads	2015	Own calculation over IMAZON roads lines
Mean terrain suitability mechanized agriculture	2011	Own calculation over CSR/UFMG
Mean slope	2011	Own calculation over CSR/UFMG
Mean geophysical agriculture suitability	2012	Own calculation over IBGE
Mean geophysical soil suitability	2012	Own calculation over EMBRAPA
Properties with environmental register (CAR)	2002-2012	Data base provided by the Amazon Environmental Research Institute (IPAM) in October 2013
Properties geo-certified	2002-2017	INCRA, updated until July 2017
Honey Production	2002-2016	IBGE Municipality Livestock Research
Milk Production	2002-2016	IBGE Municipality Livestock Research
Temporary Agriculture Area (soy, corn)	2002-2016	IBGE Municipality Agriculture Research

SCM Results

Table 2 Synthetic weights for Alta Floresta for prediction in CAR registers

Weights	Municipalities	Weights	Municipalities
0	Altamira	0,001	Nova Ubiratã
0	Aripuanã	0	Novo Progresso
0	Brasil Novo	0,358	Novo Repartimento
0	Brasnorte	0	Paranaíta
0	Colniza	0	Peixoto de Azevedo
0	Confresa	0,198	Porto dos Gaúchos
0	Cotriguaçu	0	Querência
0	Cumaru do Norte	0	Rondon do Pará
0	Dom Eliseu	0,08	Santa Maria das Barreiras
0	Gaúcha do Norte	0	Santana do Araguaia
0,214	Juara	0	São Félix do Araguaia
0	Juína	0	São Félix do Xingu
0	Marcelândia	0,096	Ulianópolis
0,025	Nova Bandeirantes	0,026	Vila Rica
0,001	Nova Maringá		

Table 3 CAR registration prediction and weights

	Alta Floresta	Synthetic Alta Floresta	Blacklist	Weights
Indigenous areas	0	0,08	0,155	0,024
Protected areas Sustainable	0	0,001	0,02	0,003
Protected areas Integral	0,015	0,011	0,022	0,013
Rural credit	425,381	674,665	1444,095	0,052
GDP (lagged)	11532,8	10181,77	12781,79	0,054
Field-based law enforced inspections (lagged)	0,01	0,004	0,004	0
Temporary Agriculture Area (soy, corn)	0,006	0,017	0,029	0,012
Properties with CAR pre-blacklist (2003-2007)	0,012	0,012	0,01	0,136
Properties w/CAR pre-intervention (2008-2011)	0,082	0,082	0,07	0,249
Population density	5,473	2,564	1,97	0,004
Farm density	0,258	0,113	0,133	0
Share of small farms	0,751	0,621	0,632	0,009
Farm per area	0,589	0,434	0,425	0,002
Number of tractors per farm	0,2	0,227	0,27	0,023
Share of land owners	83,599	86,403	79,217	0,012
Mean distance to municipalities headquarters	0,413	0,399	0,529	0,103
Mean distance to Rivers	0,067	0,058	0,041	0,014
Mean distance to Roads	0,006	0,017	0,048	0,01
Mean terrain suitability mechanized agriculture	1,046	1,089	1,149	0,102
Mean slope	8,809	9,244	9,635	0,161
Mean geophysical agriculture suitability	1,106	1,458	1,897	0,015
Mean geophysical soil suitability	6,23	11,502	10,944	0,001

Table 4 Synthetic weights for Alta Floresta for prediction in INCRA geo-certification

Weights	Municipalities	Weights	Municipalities
0	Altamira	0	Nova Ubiratã
0	Aripuanã	0	Novo Progresso
0	Brasil Novo	0.037	Novo Repartimento
0.178	Brasnorte	0	Paranaíta
0	Colniza	0	Peixoto de Azevedo
0	Confresa	0	Porto dos Gaúchos
0	Cotriguaçu	0	Querência
0	Cumaru do Norte	0.016	Rondon do Pará
0.77	Dom Eliseu	0	Santa Maria das Barreiras
0	Gaúcha do Norte	0	Santana do Araguaia
0	Juara	0	São Félix do Araguaia
0	Juína	0	São Félix do Xingu
0	Marcelândia	0	Ulianópolis
0	Nova Bandeirantes	0	Vila Rica
0	Nova Maringá		

Table 5 INCRA geo-certification prediction and weights

	Alta Floresta	Synthetic Alta Floresta	Blacklist	Weights
Indigenous areas	0	0,004	0,155	0,048
Protected areas Sustainable	0	0	0,02	0,018
Protected areas Integral	0,015	0	0,022	0,017
Rural credit	425,381	446,141	1444,095	0,039
GDP (lagged)	11532,8	6534,556	12781,79	0,015
Field-based law enforced inspections (lagged)	0,01	0,005	0,004	0,003
Temporary Agriculture Area (soy, corn)	0,006	0,017	0,029	0,012
Properties w/ GEO-CERT pre-blacklist (2003-2007)	0	0	0,003	0,306
Propert w/ GEO-CERT pre-intervention (2008-2011)	0,003	0,003	0,005	0,244
Population density	5,473	4,635	1,97	0,056
Farm density	0,258	0,223	0,133	0,015
Share of small farms	0,751	0,724	0,632	0,014
Farm per area	0,589	0,577	0,425	0,05
Number of tractors per farm	0,2	0,118	0,27	0,053
Share of land owners	83,599	68,955	79,217	0,001
Mean distance to municipalities headquarters	0,413	0,384	0,529	0,039
Mean distance to Rivers	0,067	0,03	0,041	0,003
Mean distance to Roads	0,006	0,009	0,048	0,028
Mean terrain suitability mechanized agriculture	1,046	1,269	1,149	0,007
Mean slope	8,809	9,617	9,635	0,014
Mean geophysical agriculture suitability	1,106	1,611	1,897	0,002
Mean geophysical soil suitability	6,23	9,822	10,944	0,018

Table 6 Synthetic weights for Alta Floresta for prediction in Milk Production

Weights	Municipalities	Weights	Municipalities
0	Altamira	0	Nova Ubiratã
0	Aripuanã	0	Novo Progresso
0	Brasil Novo	0	Novo Repartimento
0	Brasnorte	0	Paranaíta
0	Colniza	0	Peixoto de Azevedo
0,219	Confresa	0	Porto dos Gaúchos
0,404	Cotriguaçu	0	Querência
0	Cumaru do Norte	0	Rondon do Pará
0	Dom Eliseu	0	Santa Maria das Barreiras
0	Gaúcha do Norte	0	Santana do Araguaia
0	Juara	0	São Félix do Araguaia
0	Juína	0	São Félix do Xingu
0	Marcelândia	0,377	Ulianópolis
0	Nova Bandeirantes	0	Vila Rica
0	Nova Maringá		

Table 7 Synthetic weights for Alta Floresta for prediction in Milk Production

	Alta Floresta	Synthetic Alta Floresta	Blacklist	Weights
Indigenous areas	0	0,03	0,155	0,007
Protected areas Sustainable	0	0,032	0,02	0,001
Protected areas Integral	0,015	0	0,022	0
Rural credit	425,381	571,358	1444,095	0,002
GDP (lagged)	11532,8	8420,576	12781,79	0,005
Field-based law enforced inspections (lagged)	0,01	0,005	0,004	0,002
Temporary Agriculture Area (soy, corn)	0,006	0,012	0,029	0,016
Milk Production pre-blacklist (2003-2007)	1,727	1,747	0,514	0,481
Milk Production pre-intervention (2008-2011)	1,946	1,881	0,548	0,401
Population density	5,473	3,899	1,97	0,017
Farm density	0,258	0,203	0,133	0,001
Share of small farms	0,751	0,68	0,632	0,019
Farm per area	0,589	0,577	0,425	0,014
Number of tractors per farm	0,2	0,076	0,27	0,001
Share of land owners	83,599	85,177	79,217	0,003
Mean distance to municipalities headquarters	0,413	0,393	0,529	0,004
Mean distance to Rivers	0,067	0,03	0,041	0,006
Mean distance to Roads	0,006	0,011	0,048	0,004
Mean terrain suitability mechanized agriculture	1,046	0,845	1,149	0,002
Mean slope	8,809	13,46	9,635	0,004
Mean geophysical agriculture suitability	1,106	1,979	1,897	0
Mean geophysical soil suitability	6,23	12,798	10,944	0,009

Table 8 Synthetic weights for Alta Floresta for prediction in Honey Production

Weights	Municipalities	Weights	Municipalities
0,01	Altamira	0	Nova Ubiratã
0	Aripuanã	0,017	Novo Progresso
0	Brasil Novo	0,302	Novo Repartimento
0	Brasnorte	0	Paranaíta
0	Colniza	0	Peixoto de Azevedo
0	Confresa	0	Porto dos Gaúchos
0	Cotriguaçu	0,006	Querência
0	Cumaru do Norte	0	Rondon do Pará
0	Dom Eliseu	0	Santa Maria das Barreiras
0	Gaúcha do Norte	0	Santana do Araguaia
0	Juara	0	São Félix do Araguaia
0	Juína	0	São Félix do Xingu
0	Marcelândia	0	Ulianópolis
0	Nova Bandeirantes	0	Vila Rica
0,664	Nova Maringá		

Table 9 Synthetic weights for Alta Floresta for prediction in Honey Production

	Alta Floresta	Synthetic Alta Floresta	Blacklist	Weights
Indigenous areas	0	0,074	0,157	0,008
Protected areas Sustainable	0	0,002	0,025	0,044
Protected areas Integral	0,015	0,003	0,027	0,014
Rural credit	476,04	888,502	1623,437	0
GDP (lagged)	11993,94	12106,56	14012,33	0,087
Field-based law enforced inspections (lagged)	0,011	0,003	0,004	0
Temporary Agriculture Area (soy, corn)	0,006	0,02	0,031	0
Honey Production pre-blacklist (2003-2007)	2,529	2,593	3,291	0,058
Honey Production pre-intervention (2008-2011)	3,038	2,903	4,743	0,447
Population density	5,473	2,891	1,97	0,012
Farm density	0,258	0,235	0,133	0,027
Share of small farms	0,751	0,504	0,632	0
Farm per area	0,589	0,664	0,425	0
Number of tractors per farm	0,2	0,177	0,27	0,17
Share of land owners	83,599	85,847	79,217	0
Mean distance to municipalities headquarters	0,413	0,379	0,529	0,045
Mean distance to Rivers	0,067	0,052	0,041	0,009
Mean distance to Roads	0,006	0,013	0,048	0,016
Mean terrain suitability mechanized agriculture	1,046	1,244	1,149	0,001
Mean slope	8,809	8,059	9,635	0,001
Mean geophysical agriculture suitability	1,106	1,146	1,897	0,011
Mean geophysical soil suitability	6,23	7,614	10,944	0,049

Table 10 Synthetic Weights for Alta Floresta for prediction Deforestation rates

Weights	Municipalities	Weights	Municipalities
0	Altamira	0	Nova Ubiratã
0	Aripuanã	0	Novo Progresso
0	Brasil Novo	0,039	Novo Repartimento
0	Brasnorte	0,453	Paranaíta
0	Colniza	0,007	Peixoto de Azevedo
0	Confresa	0	Porto dos Gaúchos
0	Cotriguaçu	0	Querência
0	Cumaru do Norte	0,443	Rondon do Pará
0	Dom Eliseu	0,004	Santa Maria das Barreiras
0	Gaúcha do Norte	0	Santana do Araguaia
0	Juara	0,053	São Félix do Araguaia
0	Juína	0,001	São Félix do Xingu
0	Marcelândia	0	Ulianópolis
0	Nova Bandeirantes	0	Vila Rica
0	Nova Maringá		

Table 11 Deforestation prediction and weights

	Alta Floresta	Synthetic Alta Floresta	Blacklist	Weights
Indigenous areas	0	0.308	0.155	0
Protected areas Sustainable	0	0	0.02	0.028
Protected areas Integral	0.015	0.038	0.022	0
Rural credit	425.381	817.921	1444.095	0.008
GDP (lagged)	11532.8	11902.78	12781.79	0.294
Field-based law enforced inspections (lagged)	0.01	0.006	0.004	0.021
Temporary Agriculture Area (soy, corn)	0.006	0.01	0.029	0.106
Deforestation rates pre-blacklist (2003-2007)	0.014	0.015	0.017	0.149
Deforestation rates pre-intervention (2008-2011)	0.001	0.003	0.005	0.096
Population density	5.473	1.832	1.97	0.002
Farm density	0.258	0.226	0.133	0.002
Share of small farms	0.751	0.701	0.632	0.024
Farm per area	0.589	0.492	0.425	0
Number of tractors per farm	0.2	0.179	0.27	0.09
Share of land owners	83.599	91.682	79.217	0
Mean distance to municipalities headquarters	0.413	0.497	0.529	0.015
Mean distance to Rivers	0.067	0.045	0.041	0.003
Mean distance to Roads	0.006	0.095	0.048	0.001
Mean terrain suitability mechanized agriculture	1.046	0.978	1.149	0.074
Mean slope	8.809	10.59	9.635	0.02
Mean geophysical agriculture suitability	1.106	1.451	1.897	0.05
Mean geophysical soil suitability	6.23	8.615	10.944	0.018

5. Epidemiologically inspired approaches to land-use policy evaluation: lessons from the analysis of the Rural Environmental Registry (CAR) in the Brazilian Amazon

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Abstract: Environmental policy evaluation is crucial to determining if policy objectives were achieved. In most cases, some of the outcomes can be measured but a proper statistical analysis is difficult to achieve since the data may not represent a random sample (i.e., the data is biased), are not representative of the population or cannot be compared to a control group. This work adapts quasi-experimental statistical methods widely used in epidemiological studies that could be applied to land use policy evaluation in situations of relatively poor data. In order to test and develop this set of methods, we evaluated the effect of a land-use policy known as the rural environmental registry (CAR) on the reduction of deforestation rates in the Brazilian Amazon rainforest. The random variable of interest is the number of deforested hectares in given private properties and the statistic of interest is the difference of the annual deforestation rate between the properties before and after the policy intervention. Since no formal statistical distribution properly fit the data, non-parametrical approaches such as Monte Carlo simulations and Bootstrap were used. Data from the Brazilian states of Mato Grosso and Pará were used, with different time periods and three rural property size classes. Results show that the properties inside the Rural Environmental Registry have reduced their deforestation rates in some property classes and time periods, but this effect has not been systematic across time and space indicating that the policy is only partially effective. We conclude that the proposed statistical methods can be useful in environmental policy evaluation in different contexts due to low demands in terms of data availability and statistical distribution assumptions.

1. Introduction

Environmental policy evaluation is one of the most important, yet often neglected, aspects of policy life-cycle (Crabbé and Leroy, 2008). Policy evaluation should provide two interrelated types of analysis: the measurement of impact and the development of a counterfactual scenario (Ferraro, 2009; Greenstone and Gayer, 2009; Ferraro and Miranda, 2014). In relation to the first type of analysis, to improve environmental governance practices it is crucial to determine whether a given outcome can be attributed to a driver, program, policy or intervention. In relation to the second type of analysis, a counterfactual describes something contrary to fact, used to reduce or eliminate cofounding biases from other variables. Following studies in the natural sciences, experimental research design has become standard in an increasing number of fields. It is based on the selection of a statistically significant sample of an underlying population and the separation of the sample units into two groups: a “treatment group” and a “control group”. These two groups should be statistically similar in all respects, except for exposure to the treatment. The premise is that the randomized procedure reduces the bias, and the treatment outcomes can be compared to give a credible estimate of the effect of treatment (Campbell and Stanley, 1966; Shadish et al., 2001).

Experimental designs are difficult to apply outside of controlled laboratory environments, in situations in which it is not possible to obtain a random sample. This is the case with environmental policy evaluations in which unaffected areas, that are statistically similar, cannot be found. For this reason, approaches known as quasi-experimental designs have been created to measure the effect of given treatments. These are applied in contexts in which random selection and the strict separation of effects are beyond the researchers’ control (Campbell and Stanley, 1966; Ferraro, 2009; Greenstone and Gayer, 2009). In land-use policy evaluation criteria, socio-economic indicators (Gibbs et al., 2015) such as spatial proximity (Nepstad et al., 2006) and temporal frames (Stewart-Oaten et al., 1986; Wiens and Parker, 1995; Smith, 2002) have been used to establish the similarity between areas and to evaluate differences between areas affected and unaffected by a given policy, a concept also known as before-after/control-intervention (BACI), where the design involves a control versus treatment group, and evaluates policy by comparing the situation of an area before and after the introduction of a given policy.

Quasi-experimental research designs using counterfactual analysis aim at evaluating potential outcomes under specific scenarios, or hypotheses, such as what was the most likely scenario if the area under study had not being under the influence of a given policy (Shadish et al., 2001; Ferraro, 2009). Thus, it would be possible to investigate potential environmental benefits of the policy (e.g. how much forest had been spared in a given period due to the creation of new protected areas). For example, cellular automata (Soares-Filho et al., 2006; Vega Orozco et al., 2012), econometric (Soares-Filho et al., 2010; Arima et al., 2014) and probabilistic bottom-up models (Rosa et al., 2013; Godar et al., 2014) have been used to establish counterfactual analysis and, consequently, to measure the overall effect of environmental policies in reducing deforestation and greenhouse gas emissions.

Despite the wide variety of quantitative methods available for the measurement of policy effects and counterfactual analysis, the literature does not present methods that are both general enough to be applied across different domains and sufficiently robust to provide reliable information about the effects of environmental policies. Furthermore, most of the methods mentioned above require a vast amount of economically and spatially explicit data that is often unavailable to policy-makers, especially in developing countries. In this context, this paper seeks inspiration from epidemiology to propose a set of robust yet data-light set of methods to evaluate the effect of land-use policies (Coulston and Riitters, 2003; Tonini et al., 2009; Fei, n.d.; Tuia et al., n.d.).

Statistical epidemiological models have been applied to associate the mean behavior of the number of cases of diseases to environmental or socio-economic variables or other relevant information (Jewell, 2003; Selvin, 2004). In these models, the dependent random variable can be defined as the number of cases observed among an underlying population at risk. An appropriate statistical model for this dependent random variable is the Binomial model. If the proportion of the cases with respect to the risk population is small then the Poisson distribution can be used as an approximation to the Binomial distribution. Furthermore, if further geographical information is available then spatial clustering analysis (Lawson, 2013) can be used to detect spatial clusters in which the disease rate is significantly higher. This information is crucial for early treatment of individuals and to stop the dissemination of contagious diseases.

We argue in this paper that statistical epidemiological models can also be useful for the analysis of environmental policies such as the rural environmental registry (CAR) that is part of the Brazilian Forest Code. Created in 1965, the Forest Code (FC) was transformed during the 90's into the main Brazilian environmental federal law. The FC was revised in 2012, maintaining conservation requirements, including a Legal Reserve on at least 80% of native in private properties for the Amazon Biome. At the same time, the new FC provided an amnesty of all fines and of 58% of the areas illegally deforested in the past, while providing more flexibility for the compensation of the remaining areas with creation of the environmental reserve quota (CRA) market (Soares-Filho et al., 2014). In order to partially compensate for the amnesty and legitimization, the new FC built upon the experience of the states of Mato Grosso and Pará and created the national rural environmental registry, CAR (an acronym for Cadastro Ambiental Rural in Portuguese). CAR aims to document the degree of environmental compliance of more than 5 million rural properties in Brazil. Registry in the CAR is a voluntary initiative of the land owner, although mandatory under the FC. Benefits of joining the CAR include a lower chance of receiving fines for not complying with environmental laws, access to additional lines of credit for farmers, and the opportunity to sell to supply chains that have deforestation agreements, like those for soy and cattle (Azevedo et al., 2017).

From the perspective of epidemiology, deforestation can be conceptualized as a disease that affects an underlying population (i.e. forests), causing the decrease or death of the individuals (i.e. clearing of certain areas). Here the implementation of the CAR is assumed to be a treatment that could reduce the loss of individuals. Therefore, the proposed approach provides an example of quasi-experimental design with similarities to clinical trials and other epidemiological studies. The remainder of this paper is organized as follows: Section 2 presents the data sets for both Mato Grosso and Pará States; Section 3 presents the proposed statistical methods; Section 4 presents the results; and the discussion and conclusions are presented in Section 5.

2. The Rural Environmental Registry in Mato Grosso and Pará States

CAR is a registry implemented in the states of Mato Grosso and Pará in 2009 and 2008, respectively, with the aim to speed up the process of properties becoming compliant with Brazil's Forest Code and to improve the monitoring capabilities of the states. Thus, CAR is part of a land-use policy aiming to reduce illegal deforestation in the Brazilian Amazon. The registry contains georeferenced data of the borders, hydrography, and land-use of individual rural properties that can be combined with deforestation data provided by PRODES, a deforestation monitoring system developed by the Brazilian Institute for Space Research (INPE, http://www.obt.inpe.br/prodes/index.php). Currently, in these states there is no other dataset of rural properties as complete as CAR, and for this reason the location and land-use of these areas were not known prior to their entry in the registry. Similarly, it would be a mistake to compare the land-use dynamics of the properties inside CAR, which tend to be active farms, with indiscriminate areas outside the registry that may include public undesignated lands and other areas that are not likely to be deforested in the near future. In order to deal with this challenge, a BACI quasi-experimental design was adopted to classify the properties, for every year of the analysis, into two groups. The properties that were already registered inside CAR in a given year were considered as part of the intervention group for the policy. Conversely, the properties that in a given year are not yet in the registry but that would join CAR in a future year are considered as part of the control group, based on the assumption that they are similar to the intervention group in all aspects except for not yet being under the influence of that policy. For instance, in 2010 for the state of Pará, the properties that joined CAR in 2008 and 2009 are part of the intervention group, whereas the control group comprises those properties that will join CAR from 2011 onwards.

To ensure the robustness of the statistical analysis, a substantial number of properties had to be excluded from the study. To account for the limitation in the spatial resolution of PRODES, which is unable to detect clearings under 6.25 hectares, all properties with areas of less than 10 ha were excluded from the dataset, as were properties outside of the Amazon Biome in Mato Grosso State. Properties with an accumulated deforestation greater than 95% per year were also excluded to eliminate the possibility of the deforestation rate being influenced by the absence of forest in a specific group of properties. Properties regularized under other land and environmental policies were also excluded to avoid possible interference in the analysis of CAR's effects on deforestation. Among the properties influenced by activities of land regularization and excluded from the study are rural settlement projects from the Brazilian Institute for Colonization and Agrarian Reform (INCRA, from the acronym for Instituto Nacional de Colonização e Reforma Agrária, in Portuguese) that are quite different from the properties that make up most of the private land in Pará and Mato Grosso. In the specific case of Mato Grosso State, properties which began the process of licensing (LAU, from the acronym for Licença Ambiental Única in Portuguese) before the creation of CAR's instrument were excluded, as this is a more encompassing policy that also provides authorizations for legal deforestation. Finally, to improve the spatial consistency of the dataset, properties in CAR with more than 70% of their georeferenced area overlapped by neighboring properties were excluded because it was not possible to determine which of them were correct in the registry. In cases in which the overlap was smaller than 70%, manual inspection was used to exclude the property with the oldest CAR date. Furthermore, properties without a date of registration in CAR were excluded from our analysis. Therefore, 53.4% of the properties and 29.9% of the area from Pará State were not included in our analysis, leaving 19,466 CAR properties with a total area of 11.1

million hectares. In Mato Grosso State, 54.90% of the properties and 45.72% of the area from the original data were not included in our analysis, leaving 3,559 CAR properties with a total area of 3.1 million hectares. A more detailed description of the data for each state is given in the next section.

The dataset for both states were also subdivided to control for the effect of other factors in change of land-use. Specifically, to control for the effect of property size on deforestation rates, the dataset for both states were divided into three category groups according to their areas in terms of fiscal modules (FM), a measurement that varies for each municipality and is used as a criterion for the definition of legal rights and obligations. The first group consists of properties having up to four fiscal modules (one fiscal module represents 100 ha in most municipalities in the Amazon) that are considered “small properties” by law. In the second group are medium size properties that range between 4 and 15 FM (i.e. a property in the Amazon with 401 ha belongs to the medium size properties group). The third group are the large properties with more than 15 FM (i.e. usually more than 6,000 ha). Finally, in order to control for the effect of other regional policies (e.g. law enforcement actions, governmental subsidies) and economic factors (e.g. increases in commodity prices, variations in land price) that vary over time, the analyses were carried out with comparisons only within the same year.

Table 1 Descriptive Statistics for the Samples for Pará and Mato Grosso

Property size group (FM)	Pará		Mato Grosso	
	Properties Sampled - qty	Area Sampled Thousands ha	Properties Sampled - qty	Area Sampled Thousands ha
up to 4 FM	13,487 (69.3%)	1,270 (11.42%)	1,923 (54.02%)	282 (9,01%)
from 4 to 15 FM	3,453 (17.7%)	2,040 (18.32%)	1,041 (29.26%)	739 (23.62%)
over 15 FM	2,527 (12.98%)	7,810 (70.27%)	595 (16.72%)	2,109 (67.37%)
TOTAL	19,467	11,120 ha	3,559	3,130 ha (t)

2.1 Pará (PA) database

The sample used for Para State is described in Table 1. In Pará the number of small properties (up to 4 FM) is 13,487, 69.3% of the sample size and accounting for 11.42% of the sample area. Medium properties total 3,453 (17.7%), while occupying 18.32% of the sample area. There are 2,527 large properties (12.98%), with 70.27% of the sample area. In terms of area, small properties accounted for 1.27 million ha, the medium properties 2.04 million ha, and large properties 7.81 million ha. Therefore, the group of properties with more than 15 FM represented 70.27% all areas inside the dataset.

The time dynamics of enrollment of properties in CAR is shown in Table 2. In general, in 2008, less than 2.54% of the properties in the different size groups had been enrolled into CAR. By 2012, more than 96.5% of the properties had been enrolled in CAR.

Table 2. Dynamics of the enrollment of properties in CAR, from 2008 to 2012 in the state of Pará

Property size group (FM)	Enrollment of the properties	2008	2009	2010	2011	2012
up to 4 FM	Before CAR (control)	99.40	96.80	75.44	45.08	3.48%
	CAR	0.60%	3.20%	24.56	54.92	96.52
from 4 a 15 FM	Before CAR (control)	99.25	90.90	59.58	34.67	3.49%
	CAR	0.75%	9.10%	40.42	65.33	96.51
greater than 15 FM	Before CAR (control)	97.66	87.57	52.13	31.55	2.55%
	CAR	2.34%	12.43	47.87	68.45	97.45

2.2 Mato Grosso (MT) database

The sample used for Mato Grosso State is described in Table 1. The database of the state of Mato Grosso has 3,559 properties divided into three groups. The first group consists of properties of up to four fiscal modules with 1,923 (54.02%) properties and 9.01% of the sample area. The second group consists of properties with 4 to 15 modules with 1,041 properties (29.26%) and 23.62% of the area. The third group consists of properties with more than 15 modules and has 595 (16.72%) properties, accounting for 67.37% of the sample area. Properties with up to four FM had 282,006 ha; the second group had 739,756 ha; and the third group had 2,109,579 ha. Therefore, the group of properties with more than 15 FM represented 67.37% of the total sample area.

The time dynamics of the enrollment of the properties in the CAR is shown in Table 3. In general, in 2009, fewer than 11% of the properties in the different size groups had not been enrolled into CAR. By 2011, more than 97% of the properties had been enrolled in the CAR.

Table 3. Dynamics of the enrollment of properties in CAR, from 2009 to 2011 in the state of Mato Grosso

Property size group (FM)	Enrollment of the properties	2009	2010	2011
up to 4 FM	not CAR (control)	97.27%	41.03%	1.10%
	CAR	2.73%	58.97%	98.90%
from 4 a 15 FM	not CAR (control)	90.36%	35.74%	1.66%
	CAR	9.64%	64.26%	98.34%
over 15 FM	not CAR (control)	89.60%	40.21%	2.08%
	CAR	10.40%	59.79%	97.92%

Let Y_{it} be a random variable representing the deforested area (in ha) of property i at time t. F_{it} represents the area of forest (in ha) of property i at time t. Each property can be classified into one of three groups related to size. Let $j_{[i]}$, $j_{[i]} \in \{1, 2, 3\}$ be the index related to each size group, or simply j. For properties up to 4 FM, then $j = 1$; for properties from 4 to 15 FM, then $j = 2$; and for properties greater than 15 FM, then $j = 3$. Furthermore, each property i can be classified through time t into the CAR or Control groups. Thus, let $k_{[i,t]}$ be the index representing the CAR ($k = 1$) or Control ($k = 2$) groups) of property i at time t.

Assume that Y_{it} is a random variable that represents the number of hectares deforested in property i at time t. Let F_{it} be total number of hectares of forest in property i at time t. If Y_{it} were a discrete random variable, then one may identify the potential distribution of the random variable Y_{it} as a Binomial distribution:

$$Y_{it} \sim Binomial(Y_{it} + F_{it}, \rho_{it})$$

(1)

where ρ_{it} represents the probability of deforestation of one ha in property i at time t, $P(Y_{it} = 1) = \rho_{it}$, and $Y_{it} + F_{it}$ is the total number of forest hectares at the beginning of time t in property i. It is known that maximum likelihood estimates require the probability distribution of the observations. However, quasi-likelihood estimates (Wedderburn, 1974)requires only the relation between the mean and the variance of the observations. Thus, assuming that Y_{it} is a continuous random variable with mean $E(Y_{it}) = (Y_{it} + F_{it}) \cdot \rho_{it}$ and variance of $Var(Y_{it}) = (Y_{it} + F_{it}) \cdot \rho_{it} \cdot (1 - \rho_{it})$ then Equation 1 is also a possible approximation to the stochastic behavior of the random variable Y_{it}. However, we found that in practice, the empirical distribution of the random variable did not fit the Binomial distribution, i.e., the deviance quality-of-fit statistic (Nelder and Baker, 1972) indicated the rejection of the null hypothesis of model fit (P-value = 0.0000). Alternatives such as Poisson, Negative Binomial, Zero Inflated Poisson and Quasi-Likelihood models were also evaluated but did not fit the deforestation data.

As an alternative solution, we evaluated the first moment, i.e., the mean of the random variable, hereafter defined as $E(Y_{it}) = \tau_{jkt}$. Confidence intervals and prediction intervals were generated using Monte Carlo simulations and Bootstrap resampling techniques.

3.1 Statistical comparison of the effect of CAR using Monte Carlo simulations

Monte Carlo simulations (Dwass, 1957) are widely applied to provide statistical inference when the underlying distribution of the statistic of interest, or test statistic, is unknown. In many cases, the probability distribution of the test statistic given a null hypothesis cannot be calculated. Nevertheless, samples from the null distribution can be drawn using simulations. For example, in spatial disease clustering analysis (Martin Kulldorff 1997), the statistical inference of a cluster candidate, given the null hypothesis of spatial randomness, is conducted by randomly assigning cases to areas in proportion to their underlying at-risk populations. In sequence, the test statistic of the most likely cluster in the simulated scenario is stored. The procedure is repeated many times, say 9,999 and the p-value is the proportion of simulations in which the simulated test statistic was higher (or lower) than the observed test statistic, using the original data set. Glasserman (Glasserman, 2003), for instance, applies Monte Carlo simulations in economic settings to evaluate the performance of test statistics under simulated economic scenarios. As previously mentioned, our random variable of interest is the deforested area. We rely on statistical methods from spatial epidemiology (Lawson, 2013), since deforested areas behave similarly to observed disease cases from underlying populations, which are forests. That is, we assume that deforested areas are observed cases from an underlying continuous population of forested areas.

For each size group $j$and class k, the annual deforestation rates are calculated using Equation 2:

$$\tau_{jkt} = \frac{\sum_{j_{[i]}k_{[i,t]}} Y_{it}}{\sum_{j_{[i]}k_{[i,t]}} (F_{it} + Y_{it})} \tag{2}$$

It is of interest to test whether the deforestation rates within the different size groups ($k = \{1, 2\}$), at time t are similar. For this question, the following null hypothesis can be written:

$$H_0 \colon \tau_{j1t} = \tau_{j2t} \tag{3}$$

In practice, we want to test the null hypothesis that the deforestation rates between properties that have adopted the CAR over the years are similar to the deforestation rates of properties that have not adopted CAR over the years. For this question, we use a Monte Carlo simulation procedure to perform hypothesis testing. The algorithm is as follows:

Monte Carlo simulation procedure to test the null hypothesis of similarity between deforestation rates among properties which adopted CAR and the properties that did not adopt CAR.

For each size group and time, calculate the deforestation rates of properties that adopt CAR and properties that did not adopted CAR:

$$\tau_{j1t} = \frac{\sum_{j_{[i]}1} Y_{it}}{\sum_{i \in j_{[i]},1}(F_{it}+Y_{it})} \qquad \tau_{j2t} = \frac{\sum_{j_{[i]},2} Y_{it}}{\sum_{i \in j_{[i]},2}(F_{it}+Y_{it})}$$

(4)

Let the test statistic be the difference between the deforestation rates of properties that adopt CAR and properties that did not adopted CAR:

$$\kappa_{jt} = \tau_{j1t} - \tau_{j2t}$$

(5)

Conditional on the number of properties with non-zero deforestation at time t and size group j (n_{jt}), and the total number of deforestation at time t and size group, the distribution of the test statistic under the null assumes that the number of deforested units (in hectares) in randomly selected n_{jt} properties are proportional to the total number of forested areas in these properties:

n_{jt} properties are randomly selected with no replacement.

Let Y_t be the total number of deforested areas at time t, $Y_t = \sum_i Y_{it}$. Let $p_{i^*t} = \frac{Y_{i^*t}+F_{i^*t}}{Y_t+F_t}$, $i^* \in n_{jt}$ and $F_t = \sum_{i^*} F_{i^*t}$, be the proportion of deforested and forested areas in property i^*. In this case, under the null, it is possible to simulate the deforestation for each property i^* at time t using a multinomial distribution.

$$Y_{it} \sim multinomial(Y_t, \pi = [p_{1t}, \ldots, p_{it}])$$

(6)

S simulations are generated using the multinomial distribution. For each simulation, the test statistic (Equation 5) is calculated. Thus, a sample of the test statistic under the null hypothesis is obtained, $\left(\kappa_{jt}^{(1)}, \kappa_{jt}^{(2)}, \dots, \kappa_{jt}^{(S)}\right)$.

Finally, the values of $\kappa_{jt}^{(.)}$ are ordered and if the observed statistic is less than the 2.5% percentile or greater than the 97.5% percentile of the simulated values, then the null hypothesis is rejected at the 5% level.

In addition, P-value estimates are based on the rank of the observed statistic with respect to the simulated values.

3.2 Counterfactual of CAR policy using bootstrap resampling for statistical forecasting

Following the estimation of the annual deforestation rates for each size group, it is of interest to compare the observed values of the remaining forest areas with a hypothetical scenario in which all properties did not adopt CAR. In this case, we aim at providing further evidence of the effects of CAR policy in reducing the deforestation and, therefore, resulting in larger areas of remaining forest. To account for the estimates and the associated variability we propose a bootstrap resampling procedure.

The bootstrap resampling procedure (B. Efron 1979) is similar to Monte Carlo simulations. However, Monte Carlo simulations generally require the specification of a null hypothesis or a scenario from which samples are drawn. The Bootstrap procedure aims at estimating the distribution function F which generated the observed random sample, $Y_1, Y_2, \dots, Y_n$. To do so, it creates bootstrap samples, $Y_1^*, Y_2^*, \dots, Y_n^*$, which are random samples from the original data set with replacement. These bootstrap samples can be used to estimate confidence intervals of a test statistic of interest. For example, suppose we want to estimate a confidence interval for the sample mean, $\bar{Y}$. Thus, we can generate B bootstrap samples of size n and, for each bootstrap sample, calculate the bootstrap sample mean, $\bar{Y}_1^*, \bar{Y}_1^*, \dots, \bar{Y}_B^*$. Confidence intervals are provided using the rank of the bootstrap sample means. Further details about bootstrap estimates can be found in Efron and Tibshirani (Bradley Efron and Tibshirani 1994) and Dekking (Dekking, 2005).

In our case, we want to get samples from the distribution of deforestation rates for properties which did not adopt CAR and use these samples to forecast the behavior of all properties, if they had never been enrolled in CAR. We do this to provide further statistical evidence regarding the effectiveness of the CAR policy. Our proposed bootstrap procedure is shown next.

Bootstrap procedure to evaluate the hypothetical scenario in which all properties had never been enrolled in CAR

First, the period of interest is held fixed: $t_0, t_1, \dots, t_f$. For the state of Pará the period the simulation is from 2007 to 2012, and for the state of Mato Grosso period of simulation is from 2008 to 2011. Thus, t_0 is the baseline. The total forest area for the baseline was set as the reference level (100%).

From t_1 to $t_f$the deforestation values, and consequently, the remaining forest were estimated for all properties but assuming they had the deforestation rates of the properties which did not adopt the CAR. Thus, the forecast of remaining forest areas over the period of interest (t_1 to t_f), and for the different size groups is given by equation 7:

$$F_{j,t+1} = F_{j,t} \times \left(1 - \tau_{j2t}\right) \tag{7}$$

To account for uncertainties related to the estimated deforestation rates and, consequently, estimate the uncertainties in the forecasted remaining forests, the following bootstrap resampling procedure was used:

Using the observed values of forest and deforested areas in the database (Y_{it}, F_{it}), B bootstrap samples were generated ($b = 1, \dots, B$). Each replicate has the same size of the original database, and it has been generated using resampling from the original database with replacement. For each bootstrap sample, the rates of deforestation were calculated using Equation 8, but only for $k = 2$ (properties that did not adopt CAR):

$$\tau_{jkt}^{b} = \frac{\sum_{j[i]k[i,t]} Y_{it}^{b}}{\sum_{j[i]k[i,t]} \left(F_{it}^{b} + Y_{it}^{b}\right)} \tag{8}$$

The bootstrap deforestation rates, calculated using Equation 8, were used to forecast the deforestation and forest areas for all properties as if they had not adopted CAR in the period, starting from the original baseline forest. Equation 9 shows the forecast equation:

$$F_{j,t+1} = F_{j,t} \times \left(1 - \tau_{j2t}^{b}\right) \tag{9}$$

The 2.5 and 97.5 percentiles of the *B* bootstrap forecasts were used to create an empirical bootstrap interval with 95% confidence. These intervals represent the projection of remaining forest areas throughout the studied period, assuming a scenario in which no properties had adopted CAR.

3.3 The space-time scan statistic

The space-time scan statistic (M Kulldorff et al. 1998) aims at detecting clusters in space and time in which the observed number of cases is significantly higher than the expected number of cases, under the null hypothesis of space-time randomness. It scans the 3-dimensional space defined by the spatial geographical coordinates and the time period using a cylindrical window, as shown in Figure 1. The base of the cylinder represents the spatial component whereas the height represents the time range. Both the center of the base and the height of the cylinder are varied. By changing the location of the base, its radius, the starting and stopping times (i.e., the height) of the cylinder, different configurations are created. For each configuration, the observations inside and outside the cylinder are used to calculate a likelihood ratio statistic. The base and height configuration, i.e., the cylinder configuration with the maximum value of the likelihood ratio function (see Equations 10 and 11) represents the final cluster candidate. Secondary clusters can also be evaluated by selecting non-overlapping cylinders with large likelihood ratio statistics. Statistical inference is performed using Monte Carlo simulations, which provide statistical evidence for accepting or rejecting the null hypothesis. Further details are shown below.

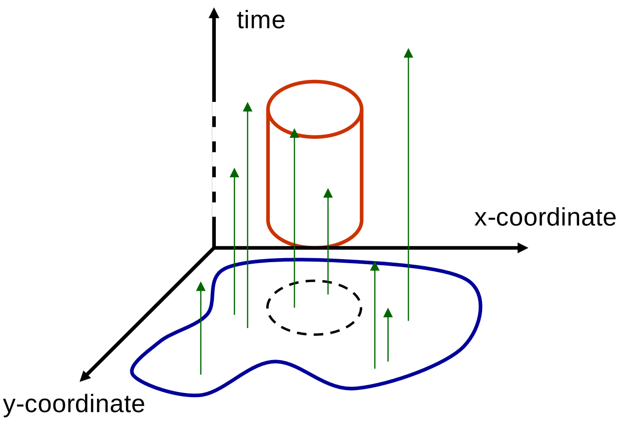

Figure 1. Space-time scan statistic using a cylinder scanning windows with variations in the height (time) and location (spatial component).

The space-time scan statistic is a widely-used method to detect clusters in epidemiological settings. In our case, we consider the Forest units as the at risk population and the deforested units as disease cases. Under the null hypothesis of space-time randomness, the deforested units are uniformly distributed in the population (Forest units). Therefore, the number of deforested units in property i at time t is Poisson distributed with the expected number of cases, μ_{it}, proportional to the size of Forest units in the previous year ($F_{i,t-1}$):

$$H_0: Y_{it} \sim Poisson(\mu_{it} = \lambda F_{i,t-1}) \tag{10}$$

where $F_{i,t-1} = F_{it} + Y_{it}$. Under the null hypothesis, $\hat{\lambda} = D/F$, where D is the total number of cases (deforested units) in space and time, and F is the total population (forest units) in space and time. Under the alternative hypothesis, there is one space-time cluster at an unknown location. Define $\boldsymbol{Z}$ as the set of all possible cylinder clusters z. For each cluster z ($z \in \boldsymbol{Z}$) let d_z and F_z be the number of deforested units and Forest units inside cluster z. The likelihood ratio test statistic associated with the most likely cluster is written as:

$$\frac{L(\hat{z}, \hat{p}, \hat{r})}{L_0} = sup\left(\frac{d_z}{\mu_z}\right)^{d_z}\left(\frac{D - d_z}{D - \mu_z}\right)^{D-d_z} \tag{11}$$

where μ_z is the expected number of cases under the null hypothesis, $\mu_z = D \cdot d_z/F$. Monte Carlo simulations (Dwass, 1957) are applied to address the statistical significance of the most likely cluster. Further details can be found in Kulldorff et. al (M Kulldorff et al. 1998) and Costa and Kulldorff (Costa and Kulldorff, 2014).

4. Results

In epidemiological settings, the number of cases of diseases can be modeled as Poisson distributed with the expected number of cases proportional to the at-risk population. Our data set has a large number of properties with zero deforested areas. For the state of Mato Grosso, 95.7% of the records have zero deforested areas. For the state of Pará 84.1% of the records have zero deforested areas. Parametric statistical models, assuming a Poisson statistical distribution or a Negative Binomial, did not fit the data., i.e., the deviance quality-of-fit statistic indicated the rejection of the null hypothesis of model fit (P-value = 0.0000). Therefore, our final analysis is based on non-parametric modeling, using Monte Carlo simulations and Bootstrap, as described in section 3.

Table 4 shows the estimated deforestation rates for each 100 ha, for each property size group and year. The Monte Carlo inference results are shown in the last column. P-values greater than 5% (0.05) indicate that the null hypothesis that the deforestation rates without CAR and with CAR are similar, was not rejected. Results show that in 2010, for properties in the state of Mato Grosso with size up to 4 FM, there is evidence that the deforestation rates between CAR and not CAR properties are different. This is also true for properties of size from 4 to 15 FM and over 15 FM in the state of Mato Grosso, in 2009. For Pará, there is statistical evidence that the deforestation rates between CAR and not CAR are different for properties of size up to 4 FM for all years, except in 2012. This is also true for properties of size from 4 to 15 FM, except in 2009. For properties of size over 15 FM there is statistical evidence that the deforestations rates are different only in 2012.

Figure 2 shows the deforestation rates for each size group from 2009 to 2011 in the state of Mato Grosso. For properties with sizes of up to 4 FM, the deforestation rates increase in the period for both CAR and without CAR properties. For properties with sizes from 4 to 15 FM, the deforestation rates have higher values in 2010 and a slight decrease in 2011 for both CAR and without CAR properties. For properties with sizes over 15 FM, the deforestation rates present a slight decrease for properties without CAR, whereas for properties with CAR the deforestation rates present a slight increase.

Figure 3 shows the deforestation rates for each size group from 2008 to 2012 in the state of Pará. In general, the deforestation rates decrease in time for both properties which have enrolled in CAR and for those which have not enrolled in CAR. Properties which have enrolled in CAR present deforestation rates smaller than those properties which have not enrolled in CAR.

Figures 2 and 3 shows that, in general, properties with sizes over 15 FM presented smaller deforestation rates compared to properties with sizes of up to 4MF, and properties from 4 to 15 FM.

Table 5 presents the total forest area for the different size groups, at the baseline period which is 2007 for the state of Pará and 2008 for the state of Mato Grosso. These values are the sum of deforested and forest areas at the baseline. They were used as the reference values (100%) in the bootstrap simulations. Table 3 compares the observed deforested and forest areas with the simulated forest areas as if the properties have not enrolled in CAR policy. In addition, upper and lower limits with 95% confidence are provided. These results are also presented in Figures 4 and 5. Figure 4 compares the observed forest areas with the simulated forest areas if the properties had not enrolled into CAR policy in the state of Mato Grosso. The observed values for properties of the size groups "up to 4 FM" and "from 4 to 15 FM" are within the lower and upper limits which suggests that the observed levels of forest conservation could have happened even if no property had adopted the CAR policy. For properties with sizes over 15 FM the simulation results suggest that if the properties had not adopted CAR policy then the remaining forest areas in 2011 would have been larger than the observed.

Figure 5 compares the observed forest areas with the simulated forest areas if the properties had not enrolled into CAR policy in the state of Pará. As opposed to what was observed for the state of Mato Grosso, for properties of the size groups "up to 4 FM" and "from 4 to 15 FM" the observed remaining forest areas at the end of the period are above the upper limit of the simulated confidence interval. This, suggests that the CAR policy succeeded in reducing deforestation rates and, consequently, resulting in larger forest area as compared to the scenario in which none of the properties had adopted CAR. It is worth mentioning that even though there was statistical evidence of the effectiveness of the CAR policy, there was no increase whatsoever in the forest area. Similarly, to the case with Mato Grosso State, for properties with sizes over 15 FM the simulation results suggest that if the properties had not adopted CAR policy then the remaining forest areas in 2012 would have been larger than the observed.

Figures 6 and 7 show the space-time cluster analysis. For visual representation of the results, a maximum cluster size parameter of 50% of the records for the state of Mato Grosso and 20% of the records for the state of Pará were chosen. Originally, a maximum cluster size parameter of 50% were applied to both states, as suggested by and Costa (Ribeiro and Costa, 2012). However, only one large cluster was detected in the state of Pará. In this case, a smaller maximum cluster of 20% was chosen in order to improve cluster detection (Ribeiro and Costa, 2012). Detected clusters with a P-value smaller than 5% (0.05) are shown in figures 6 and 7. The Poisson model was applied and, as previously mentioned, the Poisson distribution did not fit the data. Therefore, it is believed that the P-values are overestimated. Nevertheless, the results do provide important insights about areas which were more vulnerable to deforestation.

Figure 6 (a) shows that detected clusters in the state of Mato Grosso are quite small. Squares represent clusters which include only one property. Therefore, there are few areas in which the deforestation rates are higher than expected under the null hypothesis of space-time randomness. Figure 6 (b) shows that the detected clusters numbers 2, 4, 5, 6, 7 and 8 were found to be statistically significant in 2011. Clusters 1, 8 and 19 were statistically significant in 2010, and the remaining detected clusters were found to be statistically significant in 2009. Therefore, among the detected clusters, most of them happened in 2009 and 2010.

Figure 7 (a) shows that the detected clusters in the state of Pará are larger as compared to the detect clusters in the state of Mato Grosso. Cluster one has a size which is more than 20% of the state area. This cluster was detected in years 2008 and 2009. Clusters 5, 11, 15 and 17 were active in 2011, which is the last year of data. As compared to the state of Mato Grosso, the state of Pará presented larger cluster areas. The state of Pará also presented larger deforestation rates in the clusters, as compared to its global rate.

5. Discussion and Conclusion

We applied statistical epidemiological models to evaluate the deforestation rates in the states of Mato Grosso and Pará, in Brazil. Standard statistical models for count data which are the Binomial, Poisson and Negative Binomial were tested and did not fit properly the data. The data shows that most properties had zero deforestation in a given year. A zero-inflated model, was also evaluated and did not achieve a proper fit either. Thus, statistical simulation tools derived from epidemiology were developed in order to evaluate whether the governmental policy named CAR achieved its highest goal, to reduce the deforestation rates.

A statistical comparison between properties which did adopt CAR and those which did not adopted CAR in the studied period showed that the properties inside the Rural Environmental Registry have reduced their deforestation rates in some property classes and time periods, but this effect has not been systematic across time and space. This indicate that the effectiveness of CAR in reducing deforestation was only partial. For small properties, CAR seemed to have a stronger effect during the initial years of implementation but this result faded during time. For medium and high properties, alternating higher results between CAR and without CAR properties suggest that other factors than CAR may be influencing the deforestation dynamics.

Space-time cluster analysis were applied to the data in order to detect areas and time periods in which the deforestation rates were higher than the expected rate under the null hypothesis of space-time randomness. Larger clusters were found in state of Pará and smaller clusters were found in the state of Mato Grosso. The Poisson model was used in the cluster analysis but since previous statistical analysis had revealed that the Poisson model did not fit the data properly, the results represent exploratory analysis. Future works aim at developing a cluster analysis using a proper statistical model which accounts for over dispersion in the data.

As opposed to purely spatial analysis, space-time cluster analysis may indicate live clusters, i.e., clusters which comprise the last year of data, indicating that, in these clusters, deforestation may still happen in following years. Furthermore, clusters which do not comprise the last year of data indicate properties in which deforestation had decreased significantly. Results indicate smaller clusters of deforestation in the state of Mato Grosso and larger clusters in the state of Pará. Results also show live clusters in both states indicating a continuous deforestation process in some groups of properties.

This study has both policy and methodological implications. On the policy front, it indicates that CAR has not been able to reduce deforestation across the entire period and property sizes, reducing its effectiveness in small properties over time. This highlights the need of not only incentivizing farmers to join the registry but also actively use it to tackle illegal deforestation, and inform the population about the increased monitoring capabilities of the government in order to avoid deforestation. From a methodological point of view, the proposed statistical models contain some advantages over the econometric and simulation models that are currently widely applied to evaluate environmental policies. In contrast to econometric models that require detailed economic and social data (Angelsen, 1999; Pfaff et al., 2008), the proposed statistical models can be applied to situations in which such data is not available. The proposed methods also use the entire dataset without the need to calculate the difference in differences between matched subsets of samples. Similarly, the proposed statistical method provides some advantages in relation to simulation methods since it gives results that rely less on the modeler's design choices or on the assumptions of specific statistical distributions. For these reasons, we believe that the present statistical models may find a wide application of similar policy evaluation problems, especially in data-poor contexts in developing countries.

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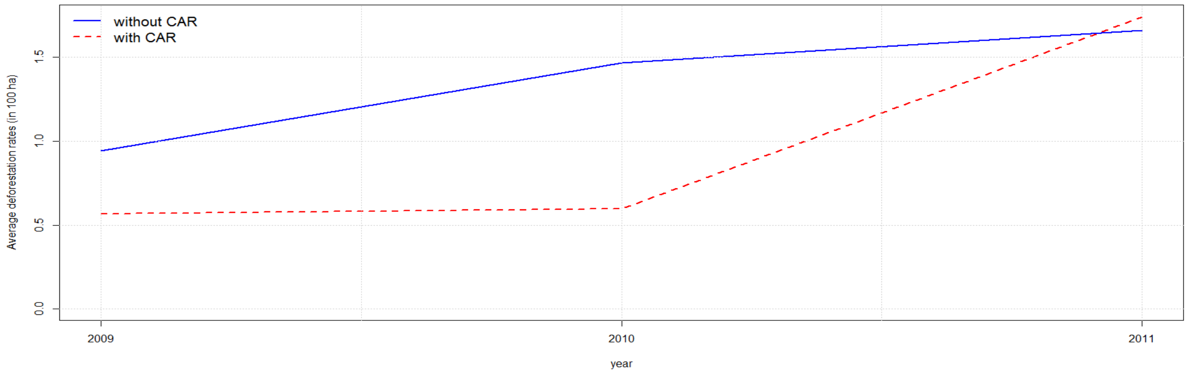
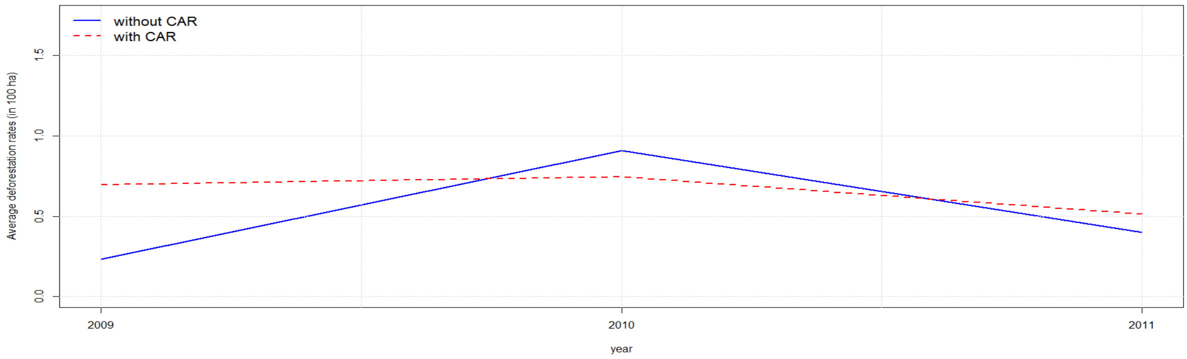
Supplements

Table 4. Comparative analysis of estimated deforestation rates between properties which adopted CAR and those which did not adopt CAR for the states of Pará and Mato Grosso

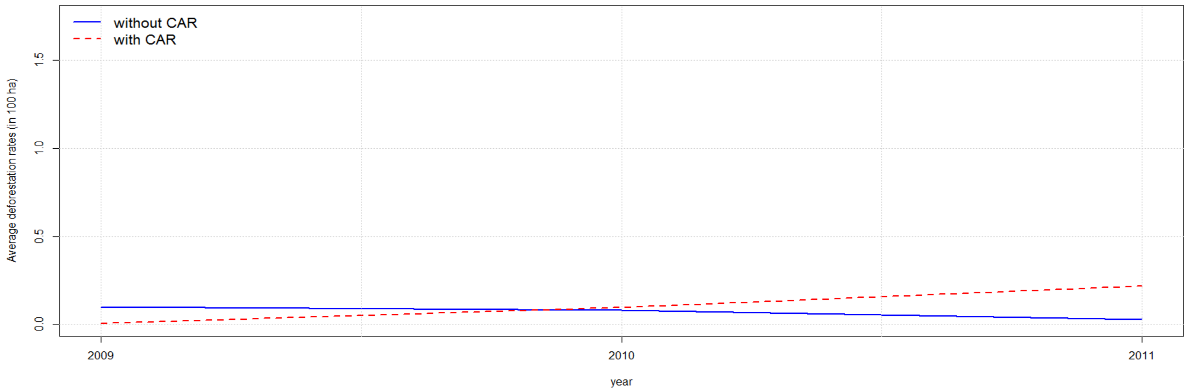
Property size group	Year	Estimated deforestation rates for each 100 ha		CAR effect in deforestation rates (CAR/control - 1)	P-valueH_0: without CAR = with CAR
		Control(without CAR)	CAR (with CAR)		
State of Mato Grosso (2009-2011)					
up to 4 FM	2009	0.9444	0.5672	-39.9%	**0.4688**
	2010	1.4685	0.5967	-59.4%	0.0137
	2011	1.6609	1.7424	4.9%	**0.5796**
from 4 to 15 FM	2009	0.2349	0.6956	196.1%	0.0162
	2010	0.9089	0.7476	-17.7%	**0.3016**
	2011	0.4001	0.5150	28.7%	**0.5675**
over 15 FM	2009	0.0988	0.0046	-95.3%	0.0258
	2010	0.0818	0.0954	16.5%	**0.3980**
	2011	0.0286	0.2201	669.9%	**0.3694**
Pará (2008-2012)					
up to 4 FM	2008	4.5769	0.9037	-80.26%	0.0002
	2009	3.5037	0.5933	-83.07%	0.0001
	2010	3.7155	2.4231	-34.78%	0.0001
	2011	2.6247	2.2073	-15.90%	0.0071
	2012	1.8443	1.6189	-12.22%	**0.2600**
from 4 to 15 FM	2008	2.9747	0.0196	-99.34%	0.0003
	2009	2.0516	1.8890	-7.93%	**0.3109**
	2010	1.4162	0.8856	-37.47%	0.0001
	2011	0.7118	0.5689	-20.08%	0.0408
	2012	0.7658	0.4002	-47.74%	0.0404
over 15 FM	2008	1.2406	1.8518	49.26%	**0.1394**
	2009	0.5014	0.6694	33.50%	**0.2722**
	2010	0.4425	0.5759	30.14%	**0.4423**
	2011	0.1604	0.2239	39.58%	**0.5452**
	2012	0.0227	0.2144	846.17%	0.0876



(a) Deforestation rates for properties with up to 4FM.

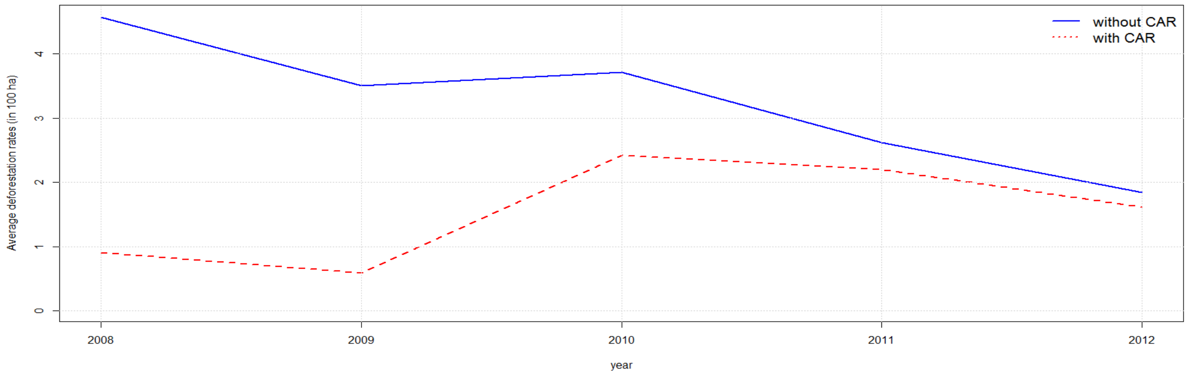


(b) Deforestation rates for properties from 4 to 15 FM.

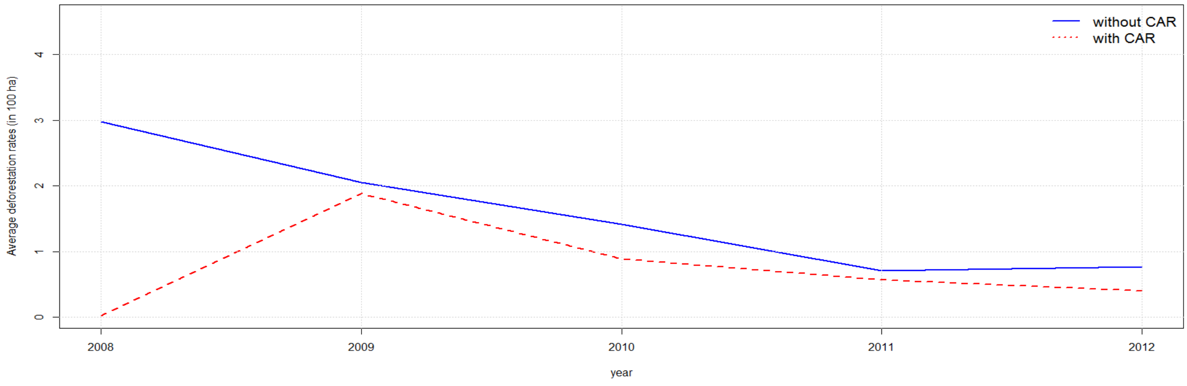


(c) Deforestation rates for properties over 15 FM.

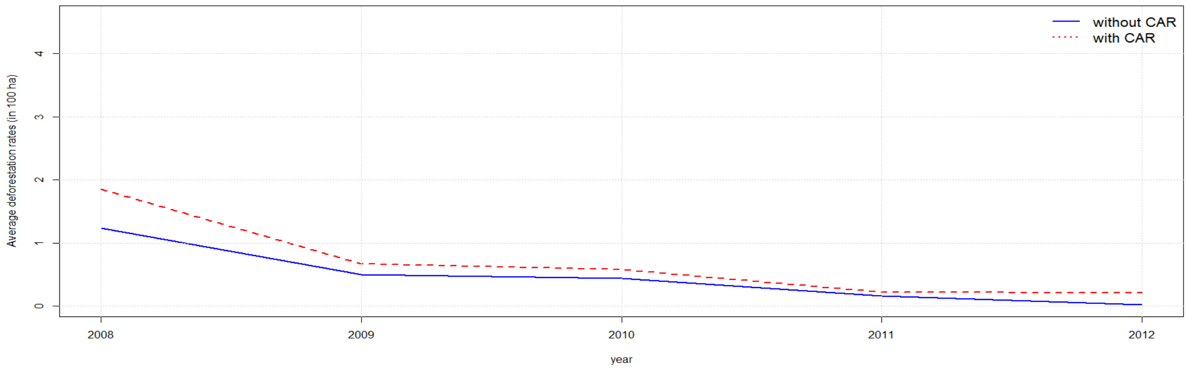
Figure 2 Mato Grosso Deforestation



(a) Deforestation rates for properties with up to 4FM.



(b) Deforestation rates for properties from 4 to 15 FM.



(c) Deforestation rates for properties over 15 FM.

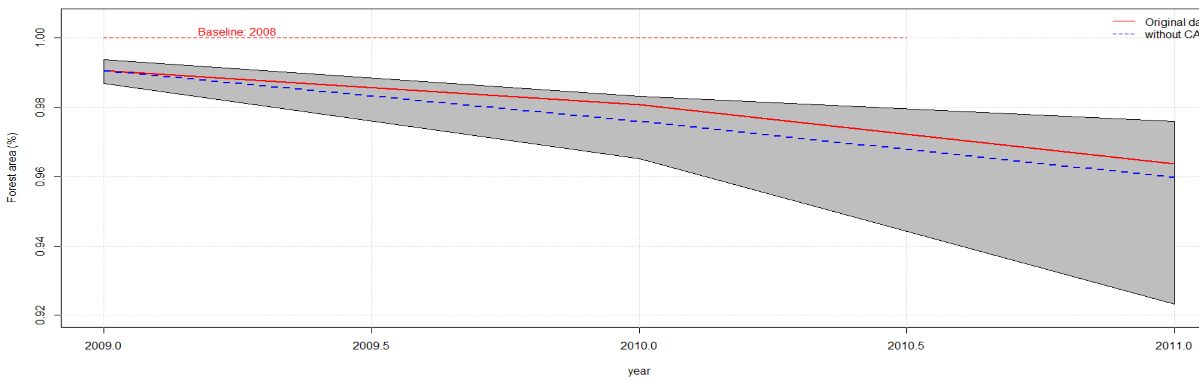
Figure 3. Pará Deforestation

Table 5. Forest areas (in ha) for the different size groups, used as baseline in the Bootstrap deforestation simulation algorithm

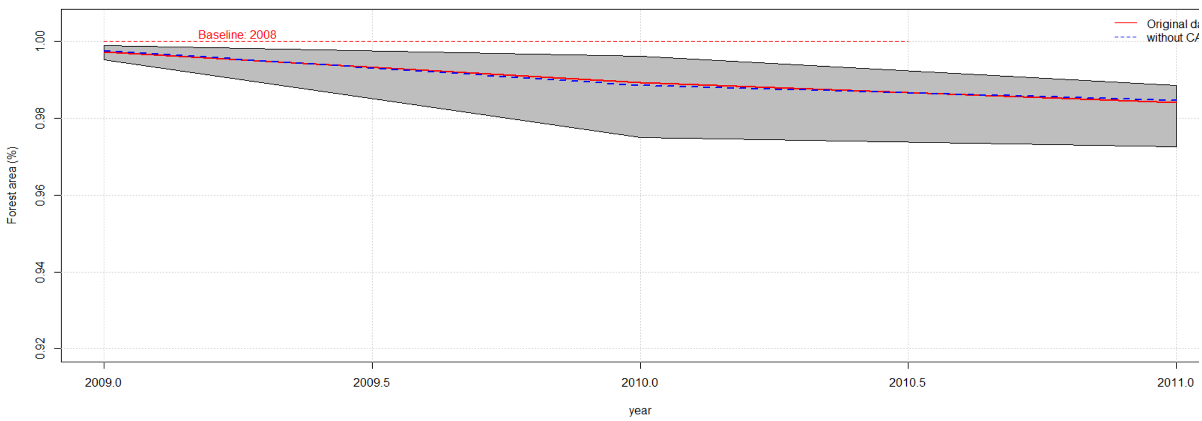
State	Baseline year	Properties size group		
		Up to 4 FM	from 4 to 15 FM	over 15 FM
Pará	2007	616.398	1.058.964	3.947.784
Mato Grosso	2008	101.474	359.345	1.253.688

Table 6. Forest areas (in ha) for the different size groups and simulated forest area as if the properties have not enrolled in CAR policy

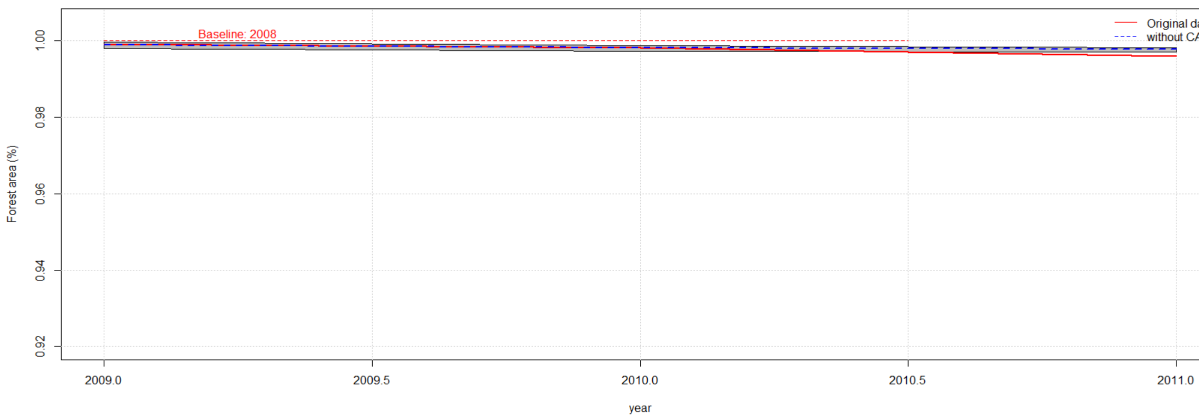
Property size group	Year	Deforestation area	Forest area	Simulated forest area (without CAR)	Lower limit (2,5%)	Upper limit (97,5%)
Mato Grosso (2009-2011)						
Up to 4 FM	2009	947	100527	100515.7	100129.5	100859.7
	2010	1000	99527	99039.6	97976.8	99739.8
	2011	1733	97794	97394.6	93808.5	99039.6
from 4 to 15 FM	2009	960	358385	358500.9	357734.5	358994.7
	2010	2902	355483	355242.4	350312.6	357990.9
	2011	1820	353663	353821.0	350128.9	355242.4
over 15 FM	2009	1157	1252531	1252449.9	1251226.5	1253175.9
	2010	1123	1251408	1251425.0	1250405.6	1252090.3
	2011	2708	1248700	1251067.2	1250126.9	1251425.0
Pará (2008-2012)						
Up to 4 FM	2008	28045	588353	588186.3	586690.1	589628.2
	2009	19991	568362	567578.2	566071.0	569137.5
	2010	19176	549186	546489.9	545100.6	547913.5
	2011	13131	536055	532146.2	530709.3	533499.0
	2012	8717	527338	522331.9	518833.3	525798.6
from 4 to 15 FM	2008	31350	1027614	1027463.4	1024017.9	1030687.6
	2009	20974	1006640	1006383.8	1002163.0	1010135.6
	2010	12374	994266	992131.2	989055.2	994627.0
	2011	6208	988058	985069.0	983109.5	986736.1
	2012	4092	983966	977525.5	972548.1	981816.0
over 15 FM	2008	49553	3898231	3898806.6	3886366.3	3908580.8
	2009	20285	3877946	3879258.0	3872354.9	3884091.5
	2010	19050	3858896	3862092.8	3856977.6	3865488.7
	2011	7452	3851444	3855897.5	3851212.5	3857985.7
	2012	7850	3843594	3855023.9	3851823.9	3855755.0



(a) Deforestation rates for properties with up to 4FM.

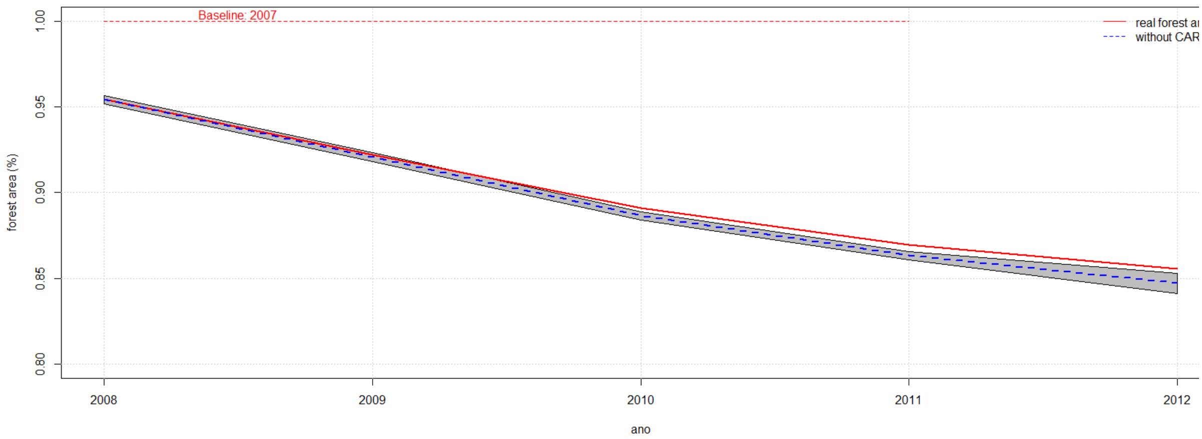


(b) Deforestation rates for properties from 4 to 15 FM.

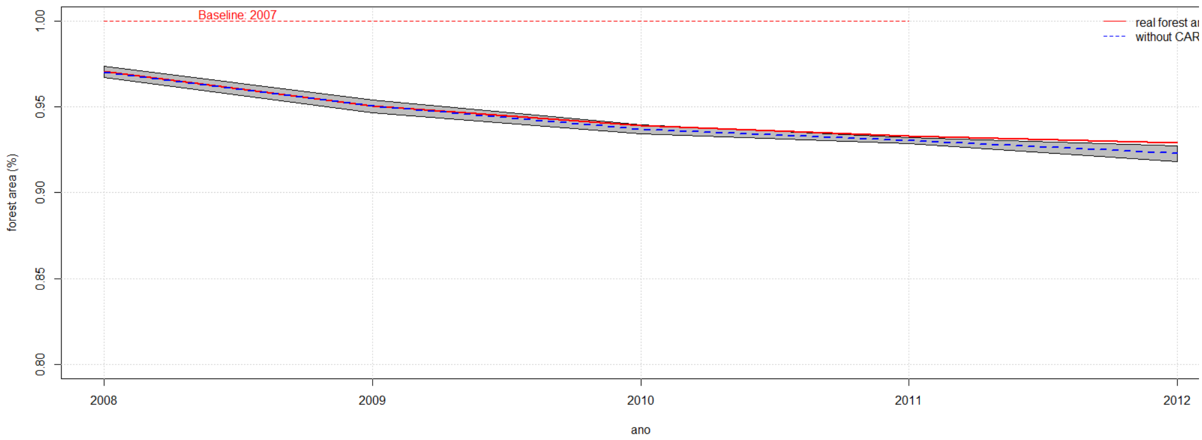


(c) Deforestation rates for properties over 15 FM.

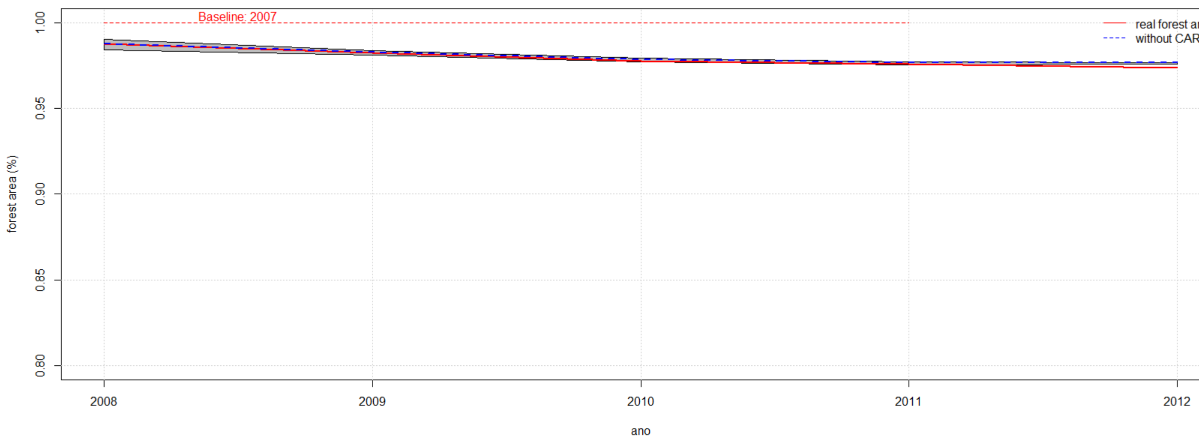
Figure 4. Simulation of remaining forest in Mato Grosso if properties did not adopt CAR



(a) Deforestation rates for properties with up to 4FM.

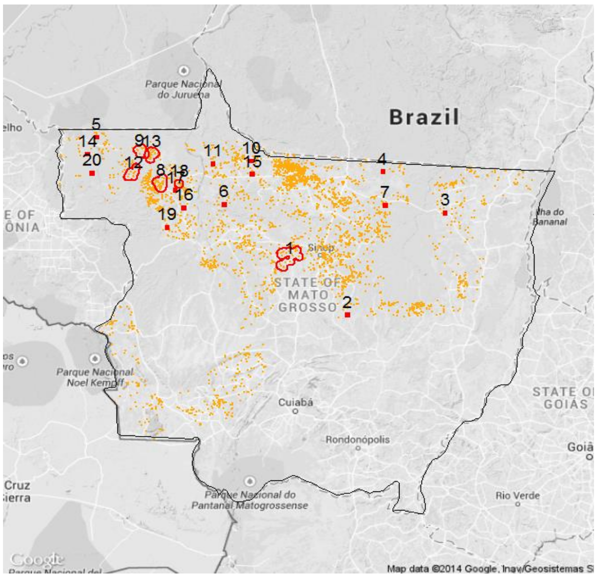


(b) Deforestation rates for properties from 4 to 15 FM.

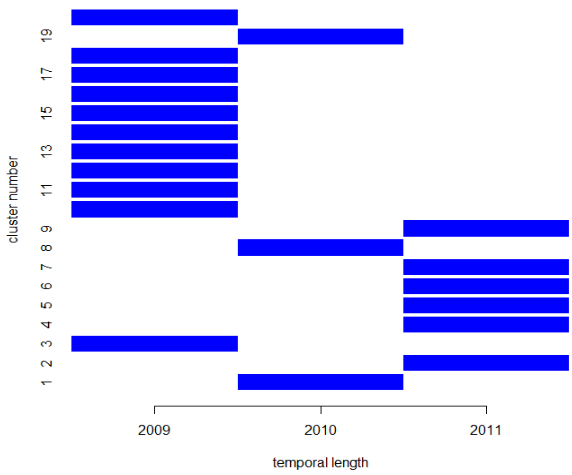


(c) Deforestation rates for properties over 15 FM.

Figure 5. Simulation of remaining forest in Pará if properties did not adopt CAR

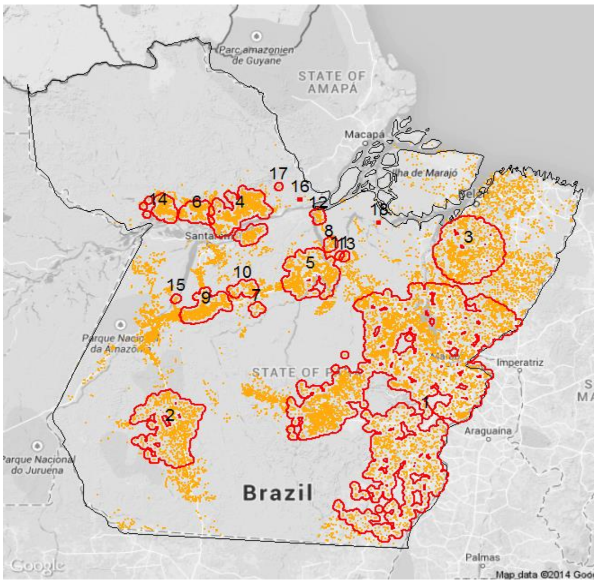


(a) Geographical location of detected clusters.

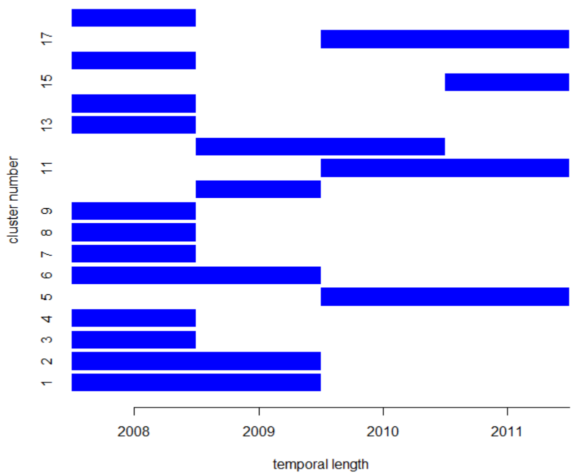


(b) Time range of detected clusters.

Figure 6. Spatial clustering analysis for the state of Mato Grosso (MT).



(a) Geographical location of detected clusters.



(b) Time range of detected clusters.

Figure 7. Spatial clustering analysis for the state of Pará (PA)

6 THESIS CONCLUSION

This thesis addressed the Amazon Fund and the resource distribution and effects of REDD+ in the Brazilian Amazon. It is possible to conclude that the Amazon Fund, one of the first large-scale efforts to deliver results-based-payments for forest carbon emission reductions, played an important role among Brazilian forest conservation policies.

Regarding the objective of outlining the financial flows from Amazon Fund to recipient projects to reveal which stakeholders, activities and geographies have received support, our findings concerning the distribution of financial resources across stakeholders, firstly, reveals great variation in adherence to the categories that distinguish rationales for the distribution of REDD+ benefits outlined by (Luttrell et al. 2013).Federal government organizations denotes a main concern with gaining control over deforestation dynamics. State government organizations have invested mostly in the implementation of various REDD+ components, including CAR, sustainable production activities and capaciting state and municipal organizations in various ways, thereby suggesting an emphasis on effective facilitators of REDD+ implementation. We found no evidence, however, that recipients of financial resources from the Amazon Fund have directly targeted high emitting or carbon preserving groups, which is surprising considering that the Amazon Fund has explicitly stated emissions reductions as its main objective.

Our findings on the distribution of financial resources across activities, secondly, indicate that financial resources of the Amazon Fund were channeled towards the direct and structural drivers of deforestation, but this was not proportional to the importance of addressing these drivers as argued by some scholars. Although we confirm that financial disbursements by the Amazon Fund are conditional upon meeting the requirements for reinvestment in deforestation reduction, we found no evidence that these disbursements were intentionally channeled according to the contribution of these activities to deforestation reductions (van der Hoff, Rajão, and Leroy 2018).

The third component of our analysis, namely the spatial distribution of financial resources, has given quite different insights into the effects of the Amazon Fund. Was observed that disbursements from the Amazon Fund to the three main recipient categories have generally benefited municipalities located in areas where deforestation threats are highest, but the study found no evidence of substantial contributions to areas with high tree cover, which are more commonly found in remote areas of the Amazon biome .Also suggests that many of the municipalities with a higher concentration of resources already had decreasing deforestation rates, while the areas that are currently under more pressure were left out.

Regarding the objective of determining the effects of the Olhos D'Água projects on deforestation, sustainable production and environmental and land ownership compliance in the munipality of Alta Floresta, this study concludes that the initiative played an important role in having this municipality removed from the blacklist of deforestation using strong evidence of an increase in CAR registration and INCRA geo-certification records of positive effects on sustainable production activities of milk and honey production, but with no effect in deforestation reduction.

These achievements are in line with other studies carried out that show that, unless these systems were used as an instrument of command and control through of the issuance of notifications and notices of infraction sent by mail, little effectiveness was obtained in deforestation reduction patterns as result of environmental registers (Azevedo et al. 2014; Rajão, Azevedo, and Stabile 2012).

Regarding the objective of determining the effect of the rural environmental registry (CAR), the larger initiative supported by AF, on the reduction of deforestation rates, , the properties inside CAR have reduced their deforestation rates in some property classes and time periods, but this effect has not been systematic across time and space indicating that the initiative is only partially effective on the reduction of deforestation.

Finally, regarding 10 years of resource distribution from the Amazon Fund and its effects on REDD+ in the Brazilian Amazon, this research concludes that the current model, whereby the Amazon Fund passively waits for projects rather than actively seek to help regions with growing deforestation may be unsuitable in the long term. This study, then, concludes by pointing to the need for developing a science-based strategy for investing the increasingly scarce resources of the Amazon Fund in order to secure stronger results in the long term. It also shows the importance of improving transparency mechanisms in order to avoid the replacement of public funds by the AF and ensure the financial additionality of international donations

Limitations of this research include that the Amazon Fund reported that 12 of its 96 supported projects were concluded by the cutoff date of this study, December, 2017. This study carried out impact evaluations on only 2 of them. A broad evaluation of Amazon Fund effectiveness should cover at least all finished projects, and further studies must be carried out to complete this research. Other limitations are linked with limited or inconsistent available data as information of CAR enrollment available only up to 2012 limiting the evaluation of the project impact in long term, several authors considerations and methodological restrictions. For future studies, the impact evaluation of additional Amazon Fund projects, as well as the study of projects using other complementary methodologies for a more comprehensive understanding of the efficiency of the Amazon Fund are recommended.

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