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PAYMENT FOR ECOSYSTEM SERVICES IN SUSTAINABLE CATTLE RANCHING SYSTEMS FOR GREENHOUSE GAS EMISSIONS AND DEFORESTATION REDUCTION: LANDSCAPE ANALYSIS IN THE BRAZILIAN AMAZON.

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Tese submetida ao Corpo Docente do Programa de Pós-graduação em Políticas Públicas, Estratégias e Desenvolvimento do Instituto de Economia da Universidade Federal do Rio de Janeiro como parte dos requisitos necessários à obtenção do título de DOUTOR em Políticas Públicas, Estratégias e Desenvolvimento.

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Defesa de Tese apresentado ao Programa de Pós-Graduação em Políticas Públicas, Estratégia e Desenvolvimento – PPED como cumprimento de etapa para obtenção do grau de Doutor.

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ABSTRACT

The aim of this thesis is to identify where and how much to pay for Greenhouse Gases (GHG) emissions and deforestation reduction when establishing sustainable cattle ranching systems. The methodology proposed in the thesis is focused on The Economics and Ecosystem Services (TEEB) proposal for agriculture and establishment of a Payment for Environmental Services scheme based on opportunity cost of agricultural lands. We developed SISGEMA model and used Dinamica EGO model to project deforestation. It is applied to the study case of Legal Amazon for avoided deforestation, reforestation to comply with Legal Reserve and cattle intensification to reduce methane emissions. The results show that using a median opportunity cost of USD $143,04/ha/year, it is possible to avoid 8,6 million deforestation hectares (87% reduction) and 3.024 million tCO_2eq of avoided emissions, with an associated annual cost of USD$ 592 million. An implicit carbon price of USD$ 4,2/tCO_2eq will generate a reduction of 3.5056 million tCO2eq. Total costs to comply with Legal Reserve in LA (10,1 million hectares), varies from USD $17,1 billion (fencing costs + opportunity costs) to USD $ 96,2 billion (scenario 1 + reforestation costs). For cattle ranching, 10% intensification can release 5,5 million hectares of pastures, 27,3 and million tCO2eq. Finally, policy analysis shows that in order to comply with Brazil´s international GHG emission reduction and deforestation commitments, it is necessary to: adjust crediting amounts and conditions of Low Carbon Agriculture and Agriculture and Livestock Plan credits, in order to promote reforestation and sustainable cattle ranching activities; promote sustainable livestock and reforestation activities in the sustainable production line of the Actıon Plan to Prevent and Control Deforestatıon ın the Legal Amazon (PPCDAm).

Key words: Avoided deforestation, sustainable cattle ranching, reforestation, methane emissions, payment for environmental services.

RESUMO

O objetivo desta tese é identificar onde e quanto pagar pela redução das emissões de Gases de Efeito Estufa (GEE) e pela redução do desmatamento ao estabelecer sistemas de pecuária sustentável. A metodologia proposta na tese está focada na proposta da Economia dos Ecossistemas e da Biodiversidade (TEEB) para a agricultura, e estabelecimento de um sistema de Pagamento por Serviços Ambientais com base no custo de oportunidade das terras agrícolas. Desenvolvemos o modelo SISGEMA e usamos o modelo Dinamica EGO para projetar o desmatamento. É aplicado ao caso de estudo da Amazônia Legal para evitar desmatamento, promoção do reflorestamento para atender a Reserva Legal e intensificação do gado para reduzir as emissões de metano. Os resultados mostram que, usando um custo de oportunidade médio de US $ 143,04 ha/ano, é possível evitar 8,6 milhões de hectares de desmatamento (redução de 87%) e 3.024 milhões tCO2eq emissões evitadas, com um custo anual associado de US $ 592 milhão. Um preço implícito de carbono de US $ 4,2 / tCO2eq gerará uma redução de 3.056 milhões tCO2eq. Os custos totais para cumprir a Reserva Legal em Los Angeles (10,1 milhões de hectares) variam de US $ 17,1 bilhões (custos de cerramento + custos de oportunidade) para US $ 96,2 bilhões (cenário 1 + custos de reflorestamento). Para a pecuária, uma intensificação de 10% pode liberar 5,5 milhões de hectares de pastagens, 27,3 milhões de tCO2eq. Finalmente, a análise de políticas mostra que, para cumprir os compromissos internacionais de redução de emissões de GEE e desmatamento do Brasil, é necessário: ajustar os montantes e as condições dos créditos da Agricultura de Baixo Carbono e do Plano de Agricultura e Pecuária, a fim de promover reflorestamento e gado sustentável; promover as atividades pecuárias sustentáveis e reflorestamento na linha de produção sustentável do Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm).

Palavras-chave: desmatamento evitado, pecuária sustentável, reflorestamento, emissões de metano, pagamento por serviços ambientais.

LIST OF FIGURES

LIST OF MAPS

LIST OF TABLES

LIST OF EQUATIONS

CONTENTS

1. INTRODUCTION

IPCC (2014) shows in its Fifth Assessment Report, that "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia". In addition, evidence of human influence on the climate system "is extremely likely to have been the dominant cause of the observed warming since the mid-20th century". Despite that fact, International negotiations on global climate agreement have not being successful: 23rd Conference of the Parties, held in Bonn in November 2017, showed that there is still much work to do to comply with 2020 commitments, commitments different from those of the Paris Agreement; there is still a need to make a balance on counties' compliance on Nationally Determined Contributions on 2018 (known as the Talanoa Dialogue); finally countries did not agree on the draft Paris 'rule book', to help monitor compliance of the Paris Agreement (Timperley, 2017).

Total annual anthropogenic greenhouse gases (GHG) emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, from 40 to 52 $GtCO_2$-eq/yr (IPCC 2014). Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are the most important greenhouse gases, reaching 47.350 $MtCO_2eq$ in 2014. Brazil is the 6th most emitting country in the world accounting for 1.356 $MtCO_2eq$ in 2014 (CAIT 2015).

In 2006, FAO releases one of the first global studies to determine the livestock sector impact on environmental problems. In particular, they made an assessment on the role of livestock on climate change and air pollution, water depletion and pollution, and biodiversity. This study shows livestock emit a considerable amount of GHG like methane, nitrous oxide and carbon dioxide. FAO (2006) also found livestock is responsible for almost 18% of total anthropogenic emissions (base year 2000), reaching 71 $GtCO_2eq$. In terms of GHG emissions by gas, livestock has a share of 9% of carbon dioxide, 37% of methane and 65% of nitrous oxide. Deforestation, an activity related to livestock sector expansion, is the main activity contributing to CO_2 total emissions, with 2,4 $GtCO_2eq$, 88% of the total 2,7 GtCO2eq. Enteric fermentation is the main contributor for CH_4, with 1.8 $GtCO_2eq$, 75% of the 2,2 $GtCO_2eq$ for livestock. For NO_2, the great majority came from manure direct and indirect management and applications, with 1,79 $GtCO_2eq$, 81% of total livestock methane module.

Gerber et al. (2013) present livestock impacts on GHG emissions, for 2005. Their main findings are:

- Total emissions of livestock are 7,1 $GtCO_2eq$ per annum, which represent 14,5 % of total anthropogenic GHG emission (estimated in 49 7,1 $GtCO_2eq$ for 2004).
- Beef accounts for 41% of sector's emission, while milk accounts for 20%.
- Feed production and processing represent 45% of sector emissions, enteric fermentation from ruminants are 39% and manure storage and processing represents 10% of total sector GHG emissions.
- Expansion of pasture feed crops into forests account for 9% of sector's emissions (included in feed production and processing).
- 44% of sector emissions are the form of CH_4, 29% N_2O and 27% (CO_2)
- Latin America and the Caribbean region generates most emissions throughout the world, with 1,3 $GtCO_2eq$, related with specialized beef, and with expansion of croplands and pastures for feed production.

1.1 Study justification

Cattle ranching represented 50% of total GHG country inventory, through Land Use Change and Forestry (LUCF) while other agriculture activities represent 12,5% during 2012 (de Acevedo & Rittl, 2014). Sectoral estimations of Brazilian 2020 Brazilian GHG emissions estimations by sector, using 2010-2012 data, show that Brazil will reduce its emissions between 36,1% and 38,9%, but will be achieving 1990 levels, if Land Use Change and Forestry (LUCF) is not accounted. Therefore, Brazil will still surpass 1990 emissions, and LUCF and agriculture participations are expected to continue growing.

ARA (2014) shows and structural change in GHG emissions by sector, when comparing 2005 with 2012: LUCF share decrease from 65% to 32%, while the agriculture sector moved from 18% to 30%.

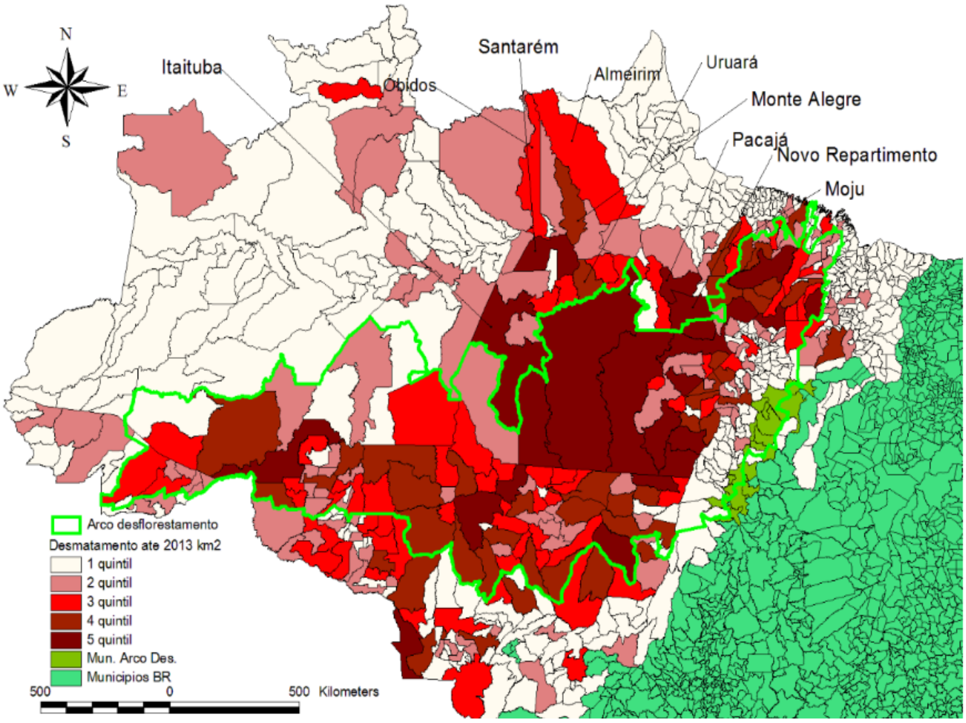
Between 1990 and 2015, Land Use, Land Use, Land Use Change and Forestry (LULUCF) and Agriculture sector (including agriculture and cattle ranching activities), most contributed to GHG emissions in Brazil. Enteric fermentation accounts for 57% of total agriculture emissions while agriculture soils account for 35% of total sectorial emissions, in 2015. Most of the activities in agricultural soils relate with cattle ranching production processes: degraded pastures, animal manure, use of synthetic fertilizers (MCTI-SEPED-CGCL, 2017). Therefore, we can conclude cattle ranching activities have a high share, within agriculture sector.

Meanwhile, Amazon biome generates most of LULUCF GHG emissions, sharing 39% of total 2015 emissions, followed by Cerrado with 39% share (MCTI- SEPED- CGCL, 2017).

GHG emission data for 2016 show Agriculture accounted for 499 $MtCO_2eq$ and LUCF 1.167 $MtCO_2eq$, from a total of 2.277 $MtCO_2eq$. LUCF share reduced in 2012, but is rising again due to increase on deforestation. A similar situation happened with Agriculture's GHG emissions, and also for enteric fermentation (323 $MtCO_2eq$) which is accounted into agriculture sector (SEEG, 2018).

This is an important process of change in the development model, and also relates to changes in sectoral GHG emissions. In a historical perspective, Brazil based its growth on agricultural commodities, like cattle, soybean and sugarcane; today, the new needs of an increasing urban population and an expanding middle class, requires new energy sources. Despite this fact, deforestation and agriculture, in particular livestock are major GHG emitting sources.

Deforestation in the Brazilian Amazon grew between 1998 and 2004 (PRODES, 2016). By 2004, Legal Amazon lost 16% (670.000 km2) of forest areas. Between 1996 and 2005, the annual deforestation rate reach 19.625 km^2/year, according to Brazilian government estimates. If this trend of deforestation continued, then deforestation projections for 2020 would be between 25.767 km^2/year and 50.604 km^2/year (Erazo, 2014). In 2004, cattle ranching activities account for 80% of the deforested area in the Legal Amazon (Presidência da República, 2004). In addition, other deforestation factors were: soybean expansion, deforestation in public lands and illegal appropriation, illegal logging, infrastructure investments (highways), new human settlements in isolated areas, internal migration because of rural poverty and land speculation.



Map 1: Deforestation arc and municipalities classified by deforestation areas quintiles up to 2013 in the Legal Amazon. Km2.

Source: calculations based on PRODES (2018)

Map 1 shows deforestation is concentrated in some municipalities along the deforestation arc[1]. Despite the above, some municipalities that lie outside the deforestation arc, presented high deforestation values up to 2013 (like Itaituba, Santarem, Pacaja, Novo Repartimento). Also, some municipalities located in the northern area of deforestation arc, also presented high deforestation values, which constitute a new deforestation arc (like Ururuá, Santarém, Obidos, Monte Alegre and Almeirim). Therefore, deforestation is a dynamic geographic process that needs to be understood through time, and implies deforestation arc boundaries are also dynamic.

Brazil had the largest cattle heard in the world during 2012, followed by India and China (FAO, 2014). Cattle ranching in Brazil, during 2013 reach a total of 207 million heads (IBGE,2014), distributed on 154 million hectares of pasture, with a stocking rate of 1,34 heads/ha. Livestock occupied between 75% and 81% of deforested areas in the Amazon between 1990 and 2005 (Barreto, Pereira and Arima, 2008). In addition, 73% of deforested area variation between 1995 and 2007 correlates to changes in cattle beef price index. Girandi (2008) state that cattle is used

[1] The Deforestation Arc is defined by the INPE (2016) as a “region where the agricultural frontier advances towards the forest and also where the largest deforestation rates of the Amazon occurred. There are 500 square kilometers of land ranging from eastern and southern Pará westward, passing through Mato Grosso, Rondônia and Acre”.

in the agricultural frontier to show that lands are productive. He found that found that after 2002 there was an intense cattle growth in municipalities located in northern Mato Grosso, northern and central Rondônia and eastern Pará. Greenpeace (2009) found similar results: cattle herd has grown in some municipalities inside the Legal Amazon, between 1996 and 2006, but in particular in the deforestation arc. Parente and Ferreira (2018) showed that opening of new grazing areas is consistent with cattle herd expansion between 2000 and 2005, in the Amazon, and MATOPIBA region. From 2006 on, pastures expansion stabilized with slight intensification in recent years.

Previous information shows a strong relation between deforestation, cattle ranching and GHG emissions. To understand their different linkages is key to identify future developments of the agriculture sector, deforestation and GHG emissions.

1.2 Objectives

1.2.1 Main objective

The main goal of this thesis is to identify where and how much to pay for greenhouse gas (GHG) emissions and deforestation reduction as a result from establishing sustainable cattle ranching systems, through a payment for environmental services scheme in the Brazilian Legal Amazon.

Specific objectives are:

a) Use environmental economic tools like opportunity costs, environmental supply curves, and pricing environmental externalities like deforestation and greenhouse gases emission, to make an exploratory analysis to prioritize areas within the Legal Amazon, and quantify associated cost of implementing a payment for environmental services (PES) scheme for deforestation and sustainable cattle ranching.
b) Make a review of selected policies associated with deforestation and sustainable cattle ranching promotion to make some recommendations based on exploratory analysis results.

1.2.2 Research questions

Justification of this thesis showed an interrelation of different problems exist in the Brazilian Legal Amazon: a) expansion of extensive cattle ranching over forested areas, b) increase of deforestation in new areas within and outside the deforestation arc and, c) important share of agriculture and land use changes of total Brazilian greenhouse gas emissions. Then the two questions that we are going to explore are:

A) How can a payment for environmental services scheme be a development strategy, and make a difference to combat deforestation?
B) Which specific policy adjustments can be suggested to promote sustainable cattle ranching and deforestation reduction?

As this is an exploratory study, we are not formulating hypothesis, then there is not going to be a hypothesis test.

1.3 Novelty and contribution

First, our results show that it's not possible to decouple deforestation control, agricultural greenhouse gas emissions and livestock management, even if a PES proposal for each sector exists. Cattle ranching expansion is one of the most important divers of deforestation (not the only one). Actual and future data on agriculture GHG emissions show that cattle ranching is the most important contributing sector. Incorporating deforestation and cattle ranching GHG emissions expand the analysis framework, helping to analyze cattle ranching dependencies, impacts and externalities to an additional level, closer to a landscape analysis. Incorporating profitability and GHG emissions aspects of sustainable cattle ranching is very important, as a first step of integrating economic systems, and environmental services for the design of sound PES schemes. Then, identification of key points that interrelate these three areas allow to design technical proposals that can constitute low carbon and low deforestation development strategies for the Brazilian Amazon.

Second, our results show that deforestation can be controlled at relative low costs, in specific municipalities in the Legal Amazon, using spatial disaggregated data, while still having a profitable cattle ranching activity, but the approach needs to be systemic, integrating different levels of analysis.

Third, results from this study allow overcoming analytical disconnection between biophysical, economic and policy analysis, based on the exploratory analysis. Also, these results allow to formulate policy recommendations and policy adjustments.

2. THEORETICAL FRAMEWORK

2.1 Ecosystem services, biodiversity and externalities

The term ecosystem services emerge as a result of several decades of discussion. Discussion about environmental pollution and resource shortages started in the 60’s and 70’s. Further, it became a discussion about economic development under the approach of sustainable development in the 80´s. In 1981, the first concept was proposed by Ehrlich & Ehrlich (1981), to bridge between concepts between social sciences and natural sciences (Braat and De Groot, 2012).

During 70s and 80s there was a great movement of scientists and activists concerned with the environment, to try to generate a conceptual framework in economic terms, and to show the dependence of society on natural ecosystems and the importance of conserving biodiversity (Braat and De Groot, 2012). The first concept of ecosystem services shows that biodiversity loss affects ecosystem functions, which affect critical environmental services for human well-being.

This historical process also produced a connection between the concept of natural capital and ecosystem services, since natural capital, understood as a limited stock of physical and biological resources present on the earth, was suffering from exhaustion and degradation. Thus, the question asked by decision-makers and researchers was how much it was possible, for economic systems, to substitute natural capital with man-made capital and the conditions for sustainable development, understood as a non-decreasing welfare throughout generations (De Groot et al., 2010).

Throughout this process, some definitions of Ecosystem Services (ES) emerge, as a concept in continuous evolution. Some of the most recognized definitions are:

A) For Daily (1997) ES are the conditions and processes in which the natural ecosystems and the species that compose it sustain human life.

B) For Costanza et al. (1997), ES are the benefits that human populations derive directly or indirectly from ecosystem functions.

C) For The Millennium Ecosystems Assessment (MEA, 2005) ES corresponds to the benefits people derive from ecosystems. ES were classified as provision, regulation, support and cultural services.

D) For the team of The Economics of Ecosystems and Biodiversity TEEB (De Groot, 2010), ES are the direct or indirect contributions of ecosystems to human well-being.

E) For the Natural Capital Coalition, the term ES is closer to Natural Capital from a business perspective, as it is the stock of natural ecosystems on Earth including air, land, soil, biodiversity and geological resources. This stock bases the economy and society through the production of value for people, directly or indirectly (FAO, 2015).

F) For the Intergovernmental Panel on Ecosystem Services and Biodiversity and IPBES (Diaz et al., 2015), ES are the benefits of nature for people (individuals, communities, societies, nations or humanity as a whole), in rural or urban environments, obtained from nature. This category includes environmental goods and services. Diaz et al. (2015), defined inclusive elements in the interaction between human societies and the non-human world, among others: nature, nature's benefits to people, and a good quality of life. In 2017, Pascual et al. (2017) defined a new concept: nature's contributions to people (NCP). Defined as is defined as "all the positive contributions, or benefits, and occasionally negative contributions, losses or detriments, that people obtain from nature" (Pascual et al., 2017).

During the last 30 years of the 20th century, a large amount of studies analyzed ecologic concerns in economic terms, starting from ecosystem services, natural capital, cost-benefit analysis of global environmental problems and costs of policy inaction (Braat and De Groot, 2012). Following these academic explorations, United Nations Environmental Program (UNEP) made a large study on the relevance of ecological systems for society, called the Millennium Ecosystem Assessment (MEA). MEA contributed to put ecosystem services in the policy agenda and expand the literature on ecosystems services exponentially (Fisher, Turner and Morling, 2009). MEA recognize four categories of ES:

a. supporting (e.g. nutrient cycling, soil formation and primary production);
b. provisioning (e.g. food, fresh water, wood and fiber and fuel);
c. regulating (e.g. climate regulation, flood and disease regulation and water purification);
d. cultural (aesthetic, spiritual, educational and recreational)

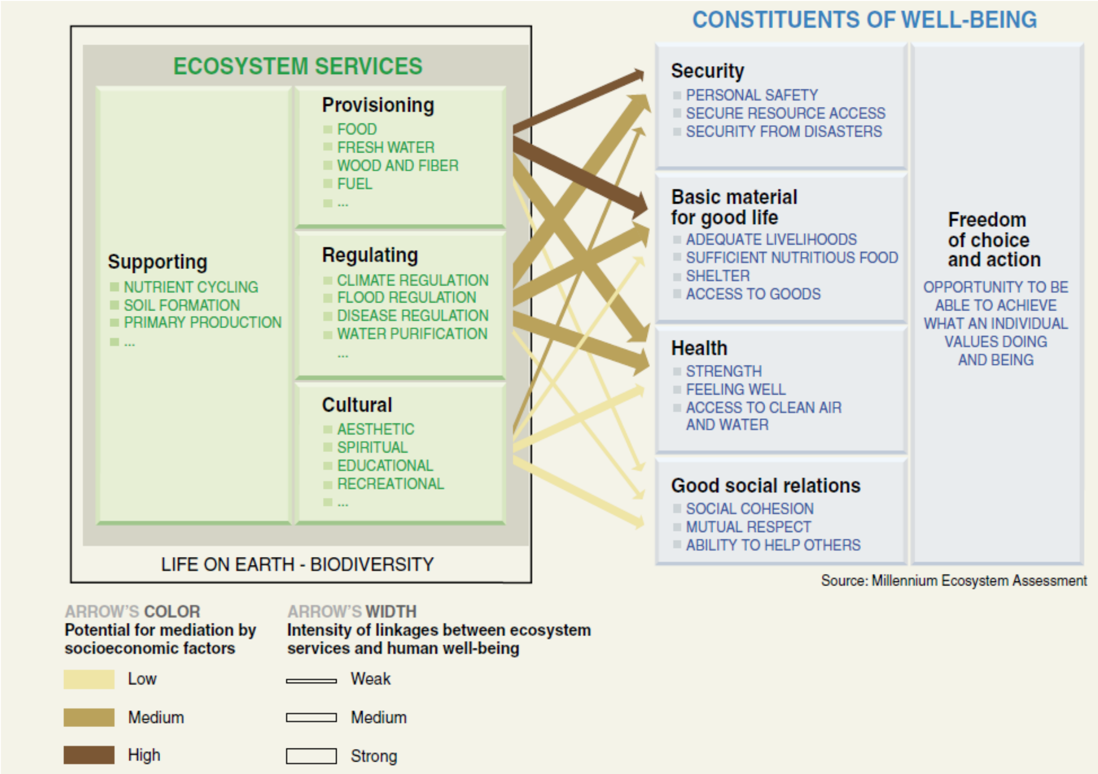


Figure 1: Ecosystem services and human well-being

Source: MEA (2005)

The introduction of these categories help to identify the transitions and relations between each category of ES, the transitions from environmental processes to environmental goods and services, and finally how are they linked with human welfare. It also helped to identify tradeoffs and complementarities between biodiversity conservation and achievement of the Millennium Development Goals (MDG), a set of goals set at the beginning of the 21st century in order to reduce poverty in its many dimensions.

MDG had a topic related with ecosystem services, in its goal 7 "ensure environmental sustainability". This goal covers a range of topics like elimination of ozone-depleting substances, marine and terrestrial protected areas increase, improved drinking water sources, improved sanitation and population living in slums. MDG did not have an analysis of changes of ecosystems goods and services, and their economic impacts.

While MDG were advancing, a huge concern rose about how to achieve the goal of significantly reduce biodiversity loss up to 2010, as part of the meetings of the Convention on Biological Diversity (CDB). In addition, the Stern Review of the Economics of Climate change identified a need of early action and policy change. In 2007, during a meeting of environment ministers from the G8 +5 group in Potsdam, a joint initiative rose to "draw attention to the global economic benefits of biodiversity and the costs of biodiversity loss and ecosystem degradation", based on the CBD goals and the Stern Review momentum (Sukhdev, 2008). They proposed a framework for valuing ecosystem services that comprise the following steps (Sukhdev, 2008):

a) Examine the causes of biodiversity loss
b) Evaluate alternate policies and strategies that decision makers are confronted with
c) Assess the costs and benefits of actions to conserve biodiversity
d) Identify risks and uncertainties
e) Be spatially explicit
f) Consider the distribution impacts of biodiversity loss and conservation

This framework is known as The Economics of Ecosystems and Biodiversity (TEEB). De Groot et al. (2010) made a proposal to operationalize this framework, ensure that ecosystem services had a robust and credible science and to generate clear messages for decision makers.

The way to connect ecosystems with human well-being starts from an anthropic view, since "a service is a service if a human beneficiary is identified" (Potschin and Haines-Young, 2011). Similarly, the term service corresponds to a label of the useful things that ecosystems do for people directly or indirectly (De Groot et al., 2010). In their methodological proposal, Potschin and Haines-Young (2011) also show a separation of benefits and values, since different benefits can be valued differently by different groups of users at different times, and in different places.

Although ecosystems and biodiversity generate important inputs for human welfare, there is still a large-scale loss of biodiversity and degradation of ecosystems. Economic benefits of sectoral outputs are well identified, but economic costs of externalities are not, hence, they are not considered in policy making and investment decisions (Bovarnick and Alpizar, 2010). An externality can be defined as "an unbalanced provision of an ecosystem service (positive externality) or a non-penalized negative effect on the provision of an ecosystem service (negative externality)" (FAO, 2016). Externalities can also be defined as "a state in which (i) the actions of an economic agent in society impose costs or benefits on other actors in society; and (ii) these costs or benefits are not fully compensated and therefore are not part of the decision-making process of the agents " (TEEB, 2015).

Difficulties in public policy and in private decision making arrive because ecosystem services are mixed public goods, use levels are difficult to regulate, there is poor information on ecosystems and there are institutional failures that lead to problems of management and governance (De Groot et al., 2010). In addition, costs of ecosystems services degradation are difficult to measure, and increase scarcity of them put at risk human production of goods and services based on them, limiting the capacity of reducing poverty and generating human wellbeing (Bovarnick and Alpizar, 2010). Therefore, markets are giving the wrong signals, which in turn difficult policymaking process. If we don't want to go further from a tipping point, a point of no return, "fundamental changes are need in the way biodiversity, ecosystems and their services are viewed and valued by society" (De Groot et al., 2010).

Some authors have shown that economic valuation has many advantages that support its implementation in SE valuation processes and can help overcome market failures in order to try to internalize these not accounted costs (see Annex 1 for a discussion on valuation and methodologies). Baldock (2015) shows that at the core of discussions to prevent environmental degradation, economic valuation helps to identify resource management efficiency. Companies and policymakers employ decision-making tools such as Cost-Benefit Analysis (CBA), in which each of the costs and benefits must be in monetary units. In this way, a decision process can be generated on impacts (positive and negative), trade-offs, distributive effects and return on investment (Baldock, 2015). Economic valuation creates a bridge between economic considerations and sustainability initiatives, since it not only reports, impacts, dependencies and costs associated with companies´ shareholders, but also translates environmental and social values into the monetary values (Truecost, 2015).

For Pascual and Muradian (2010), an economic valuation can be a useful tool when:

a) There are non-existent markets for goods and services of biodiversity
b) Imperfect markets and market failures exist
c) For some environmental goods and services, it is necessary to understand their alternative uses
d) There is great uncertainty regarding the demand and supply of natural resources, especially in the future
e) Governments may use valuation in comparison with market prices to design conservation programs
f) Valuation is a requirement to reach a natural resource accounting, using methods such as net present value.

Non-existent markets, imperfect markets and market failures are very relevant when analyzing ecosystem services in agriculture and food production sector, because they generate what has been called visible and invisible flows (TEEB, 2015). In this sector, different benefits are generated and received from ecosystems and are turned into agricultural activities, such as cattle ranching, which generate some costs on ecosystems. When productive activities do not take into account costs on ecosystems and benefits they generate, there is a reduction of production due to the decrease of the SE; costs are generated outside the production/manufacturing places that are not covered by companies; public sector is losing revenue by having activities with high subsidies and low taxes (e.g. fishing); and future production costs can increase as a result of ES reduction (Bovarnick and Alpizar, 2010). Consequently, agriculture and food production systems have great potential to generate benefits for society as food for humans, food for the livestock sector, fibers for the artisanal and industrial sector, raw materials for biofuels, employment and cultural cohesion. Agricultural systems also receive benefits from ecosystems that are not accounted for, as fresh water, nutrient cycling and pollination, thus becoming "economically invisible ecological inputs" and not part of the decision-making process (TEEB, 2015).

The above examples show that markets fail in the efficient and effective allocation of resources and one of these failures relates to externalities (TEEB, 2015). In this way, economic valuation allows to assess the positive and negative externalities that generates from and towards biodiversity and ecosystem services, and to and from agricultural and food production systems. Thus, it is possible to adjust private benefits and costs so that they reflect societies' true costs and benefits, so costs become social opportunity costs (FAO, 2016). By adjusting these benefits and costs, it is possible to identify the different impacts that different agricultural or sustainable production practices have on the structure and functioning of ecosystems, and how society value them in an integral way.

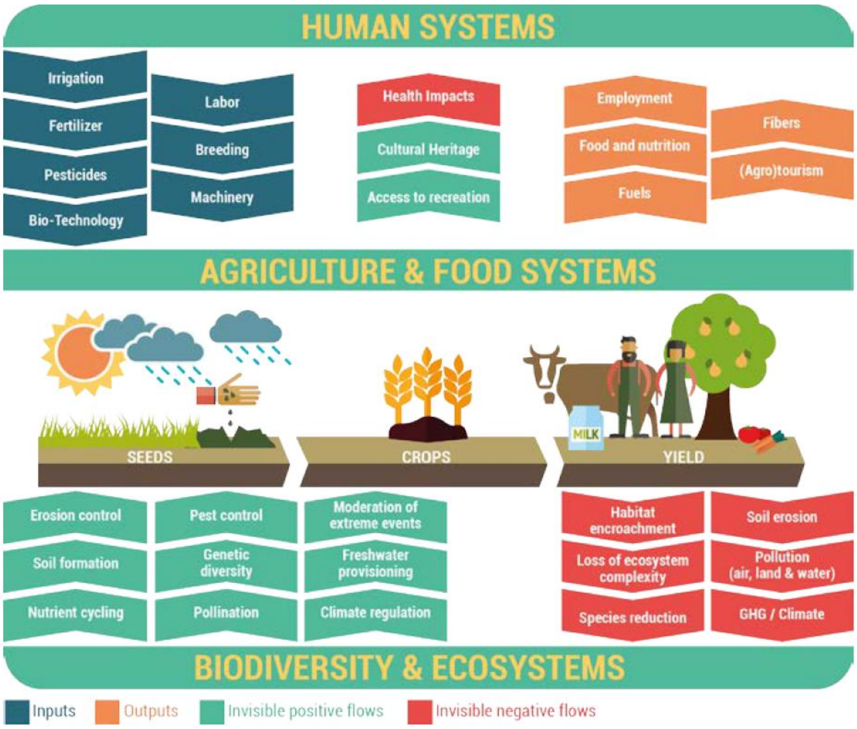


Figure 2: The visible and invisible floes of agricultural products

Source: TEEB (2015)

Figure 2 shows how TEEB (2015) identified externalities in the agriculture and food production systems. This graph shows the interrelations between the different agricultural and food systems, biodiversity and ecosystems and finally the anthropic systems. It shows the visible and invisible flows (externalities) between these systems, in a perspective of systemic thinking, not isolated systems, which in turn allows evidence of dependencies and impacts. For traditional cattle ranching practices, it is clear that several invisible flows exist: greenhouse gas emission from deforestation to create pasturelands, soil erosion as a result of vegetation cover loss, methane emissions, loss of ecosystem complexity because of landscape homogenization.

A key point in the process of externalities analysis is recognition of interactions between the analyzed systems (human, agricultural and natural) and the contribution of different types of capital to these interrelationships: natural capital[2], physical capital[3], human capital[4] and social capital[5] (TEEB 2015).

Once externalities are evaluated and transformed into economic values, this information is translated to decisions makers and policy makers. Kosmus, Renner and Ullrich (2012) identify an important step to clearly influence governance and decision making areas: appraising the institutional and cultural framework. This step generates information on policies, regulations, informal rules, as well as key authorities that influence ecosystem management.

The approach is better suited for actions at local and regional level, because information used for different analyses vary according to different levels of aggregation (Kosmus, Renner and Ullrich, 2012). In addition, different types of entry points are identified to mainstream ecosystem services into policies with policy options like:

a. Providing information: indicators and green accounting systems, integrating values of ecosystem services into policy assessment

b. Setting incentives: fiscal and market based such as payments for ecosystem services, certification and labelling, reducing harmful subsidies, biodiversity offsets, emissions charges, environmental taxes, etc.

c. Planning and regulation use: e.g. guiding land use decisions through spatial planning and environmental assessment, protected areas, investments in ecological infrastructure.

Changes in different policies have the ability to influence in indirect and direct drivers of biodiversity and ecosystems change and degradation, which in turn will help to recover the ecological structure and maintain key ecological processes.

May et al. (2012) state that reducing deforestation in the Brazilian Amazon has been possible "through a combination of regulatory norms and market mechanisms, but the most effective instrument mix is as yet unknown". Then, it is important to analyze how "different policies and economic instruments interact with each other in what has been called a policy mix". A policy

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[2] Definition of Natural Capital is the limited stock of physical and biological resources found on Earth. It also refers to the ability of ecosystems to provide ecosystem services.

[3] Physical capital definition is the accumulation (stock) of value inherent in the quantity and quality of machinery, manufactured goods and bonds.

[4] Definition of Human capital is people and their ability to be economically productive. Education, training and health care can help increase human capital.

[5] Social capital is assumed as the inherent value of relationships and networks between people and institutions that allow society to function more effectively.

mix for biodiversity conservation can be defined as "a combination of policy instruments, which has evolved to influence the quantity and quality of biodiversity conservation and ecosystem service provision in public and private sectors" (Schröter-Schlaack and Ring, 2011). For Barton et al. (2014) policy instruments can be viewed as a continuum of different alternatives that go from government to market instruments, including direct regulation, economic (dis) incentives, and facilitation of self-regulation.

Some of the policy elements that can be evaluated are: a) conservation goals and effectiveness, b) economic benefits and costs; c) social impact and legitimacy, and; d) institutional and legal constrains (May et. al, 2012). It is also important to analyze different sectoral policies that are in synergy or conflict with forest ecosystem services or biodiversity conservation. For Barton et al. (2014), additional policy mix criteria correspond to institutional fit, efficiency, effectiveness and equity, but thinking on going further using different complementary tools like GIS to describe spatial variation of opportunity costs, distributive justice, and how ecological characteristics at different level can influence policy effectiveness.

An interesting example of policies that incorporate multiple ecosystem services is Reducing Emissions from Deforestation and Forest Degradation (REDD+). REDD develop a framework in which developing countries are rewarded financially for any emissions reductions achieved associated with a decrease in the conversion of forests to alternate land uses (Parker et al. 2009). But REDD+ not only relates with deforestation and GHG emissions, there are other important co-benefits that are generated while implementing REDD+ policies. The broader dimension of co-benefits is related with (Brown, Seymur and Peskett 2008):

- Social co-benefits associated with pro-poor development
- Protection of human rights an improvement in forest governance
- Environmental co-benefits enhanced biodiversity protection and, soil and water quality and availability.

Annex 11 has a more detailed analysis on co-benefits and the importance for REDD+ policy design.

2.2 Deforestation from an environmental economics perspective

Understanding of forest dynamics is key factor to identify potential areas for payment for environmental services (PES). Angelsen et al. (2001) showed that different causes of deforestation are related with immediate causes (like markets, technology or institutions) and underlying causes (like macroeconomic variables). In addition, poverty and population growth (a Malthusian population approach), and markets, prices, costs and property rights (market approach) are some of the main explanation lines in deforestation analysis. All this debate is confusing because there is a jump between approaches and there is no clear distinction in formal models between immediate causes and underlying causes. Angelsen (2010) and Angelsen & Kaimowitz (1999) classified causes of deforestation at three different levels: a) deforestation agents, which comprises individuals, households or companies, along with their characteristics and activities, which in turn are the source of deforestation; b) immediate causes, are external factors that influence agents decisions, such as prices, market outlets, technologies and agro-ecological conditions, new information, access to services and infrastructure, they constitute the incentives for different choices; c) underlying causes, influences immediate causes by broader national or international macro-level and policy instruments.

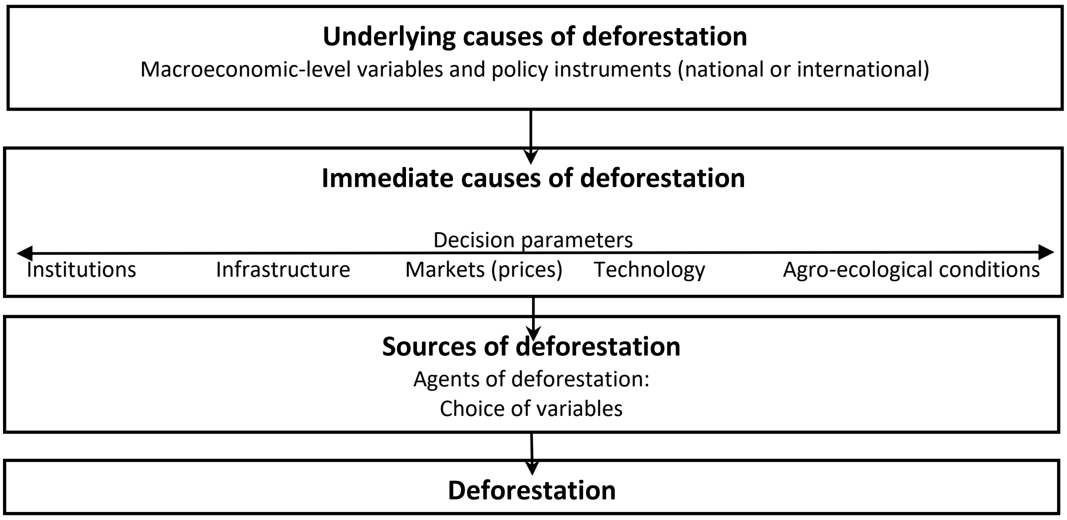


Figure 3: Variables affecting deforestation

Source: adapted from Angelsen and Kaimowitz (1999) and Angelsen (2010)

The previous figure shows that microeconomic models tend to analyze immediate causes of deforestation, while macroeconomic models tend to analyze the underlying causes of deforestation. The influence of variables is form the upper level to the lower level. There is a possibility of generating feedbacks between levels, but for sake of simplicity, the model analyzes one-way influence.

Underlying causes of deforestation are difficult to relate with deforestation because macroeconomic variables influence decisions through complex paths and indirect relations (Angelsen and Kaimowitz 1999). In the following sections we will discuss about models for immediate causes of deforestation and decision making as a source of deforestation form a neoclassical and post-Keynesian perspectives.

2.2.1 Neoclassical basic deforestation model:

Deforestation has an important impact on ecosystem services like reduction of soil fertility, loss of homelands for indigenous people, disruption of water systems, resulting in increased likelihood of extreme hydrological conditions and subtle alteration of local climates; also, loss of potential future income associated with biodiversity, genetic resources, recreational amenities and future tourism potential (Perman et al. 2013). Angelsen and Kaimowits (1999) state that economic models focus on immediate causes of deforestation. One interesting cause is related with conversion of forest land to other uses, primarily, agriculture and ranching, which offer a higher financial return than the one from natural forests (Pearman et. al 2011). These decisions may seem to be optimal form land owner point of view. Then, tropical deforestation is a result of incentive structure that exists, and it suggests that changing land owner decision making is based on altering those incentive structures (Pearman et. al 2011).

Hartwich (1992) and Barbier and Burges (1997) developed some of the first models to understand deforestation from an economic point of view, based on a general equilibrium model, in which deforestation can be explained as a rational decision that tries to optimally allocate forest land between competitive uses: timber, agriculture and forest levels. Results from these models suggest that, in the presence of deforestation externalities, use of taxes on households is adequate to internalize soil erosion and reduction of carbon capture capacity form reduction of forests (Hartwick, 1992). Also, if environmental benefits associated to forests are not included in opportunity costs of converting forest lands to agriculture, then a reduction on marginal costs of forest conversion, a supply curve for forest conversion, will occur, resulting in lower prices for converted forest land and higher levels of deforestation, equivalent to a shift of supply curve to the right (Barbier and Burges, 1997).

2.2.2 Forest transition theory

Meyfroidt, Rudel and Lambin (2010) argue that in order to reduce deforestation rates it is necessary a better understanding of economic, political, and biophysical conditions associated. Angelsen (2010) showed that deforestation is a result of changing forests into space for crops and cattle; therefore, it seems that humanity is facing an unpleasant choice between “conserving forests” and “feeding the hungry”. Forest Transition Theory (FTT) helps us to understand different deforestation drivers. In particular, FTT describes a “sequence over time where forested region goes through a period of deforestation before the forest cover eventually stabilizes and starts to increase. This sequence can be seen as a systematic pattern of change in the agricultural and forest land rets over time” (Angelsen 2007).

Forest Transition Theory (FTT) was first proposed by Rudel and Mather between 1992 and 1998. Forest cover declines and slowly increases again, is an observation from the 19^{th} century in several European countries like Denmark, France and Switzerland. Agricultural yields increase and seem to help reverse the decline in forest cover (Angelsen and Kaimowitz 2001). Forest contraction and expansion is related with a progressive adjustment of agriculture to land capability, so, “agriculture is located on better quality land, production increase for a given amount of means, and us other land areas are released and made available for reforestation” (Robertsen 2011).

Lima (2012) stated that FTT is based on the Environmental Kuznets Curve, used to describe pollution and economic development. FTT it’s an adaptation, where pollution concentration was adapted to deforestation: in initial stages of economic development, deforestation will increase, and later, after industrialization processes begins, deforestation start to reduce, when reforestation forces are bigger than deforestation forces. This land sparing process form agriculture, should not only be related to forest areas, because relocation to natural states areas, with potential of providing ecosystem services, can include, savannas, prairies and woodlands (Walker 2012).

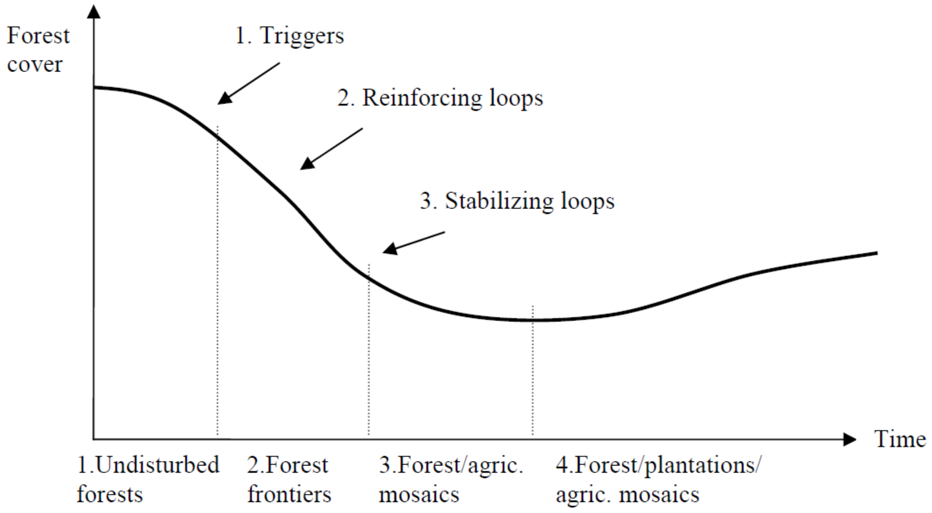


Figure 4: Stages and main drivers in the forest transition

Source: Angelsen (2007)

The FTT present 4 stages (adapted from Angelsen 2007, Robertsen 2011):

1. Stage 1: undisturbed forests with high forest cover and low deforestation. Extraction occurs with a vision of unlimited resources and regardless of future impacts. The area is not accessible for commercial production; therefore, there is an unintentional and passive protection. Accessibility increases as infrastructure (roads) or economic development increases. Low pressure on forests because of low population densities. This seems to be the case for Northwest Amazon basin.

2. Stage 2: acceleration and high deforestation, increasing forest scarcity because of growing urban incomes, high agricultural demand and urbanization. Complemented by booming agricultural exports (beef and soybean in Brazil). This stage is characteristic of forest frontiers.

3. Stage 3: slow-down of deforestation and forest cover stabilization. There are forests and agriculture mosaics, forest cover reaches an absolute minimum, or disappear. Forest covers stabilization. Implementation of policies help increase reforestation as society perceives forest resources as scarce, and it is a socially desirable and economically optimal activity. There is an agricultural adjustment and concentration to more fertile land.

4. Stage 4: reforestation activities in place, because of forest policies for planting trees or direct regulation (protection forests), and sustainable forest management practices

(along with certification schemes) and payment for environmental services (PES) schemes (carbon, water, biodiversity). At landscape level, forests coexist with agriculture, plantations, and forest mosaics.

During the first stage (undisturbed forests), a set of triggers start deforestation process, which accelerates through a set of reinforcing loops, leading to the second stage

Triggers in first stage are primarily related to roads and to population growth. Road construction (new and better) is a result of new market opportunities (large price shifts in agricultural commodities or timber), technological change that make agriculture on previous forest lands more profitable or political consideration like "state-making" (get control over the national territory), promoting rent seeking activities. Population growth and movement of people in the form of resettlement programs is also an important trigger.

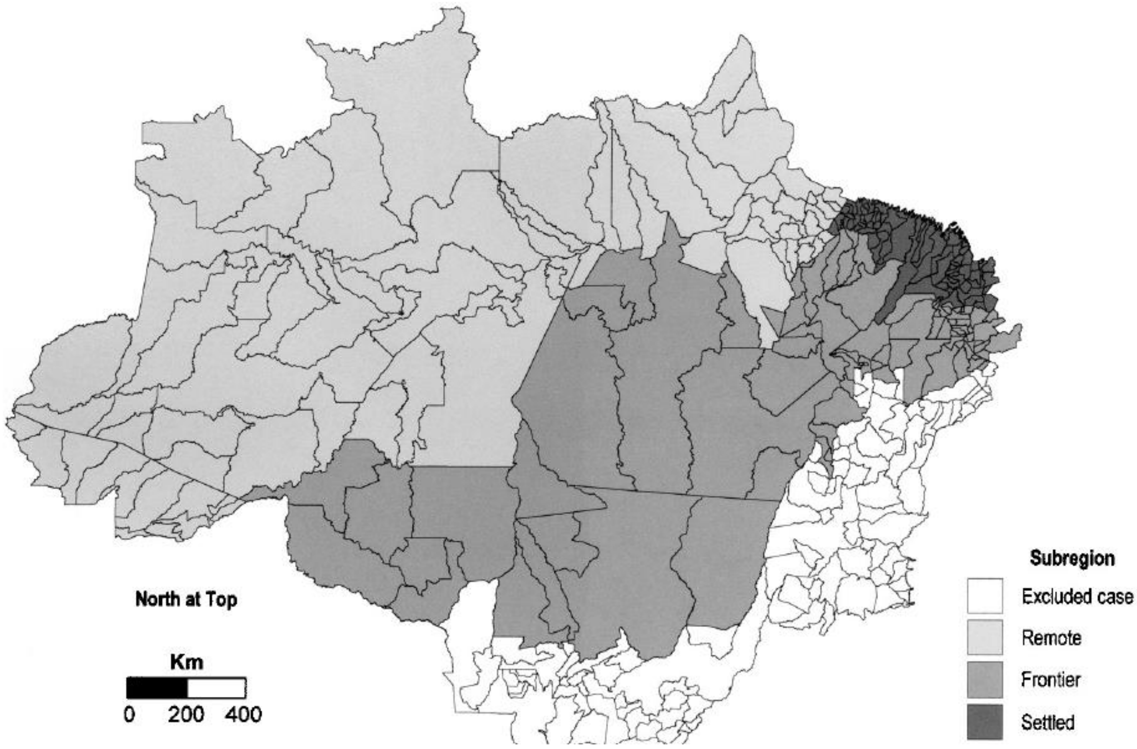
Reinforcing loops are positive feedbacks that increase initial effects in the second stage (forest frontier). They relate with population and economic growth, and generate an increase on agricultural prices (land rent), through increased local demand for agricultural products and the development of downstream processing activities for agricultural products (i.e. slaughterhouses).

Access and reduced costs of agricultural inputs also increase agricultural land rent in reinforcing loops. First, capital accumulation allows reinvestment in forest degrading activities. Immigration provides additional labor supply, which will reduce local wages. Additional population stimulate better infrastructure and transportation facilitates, which in turn reduces transportation costs and increase agricultural rents. Finally, an "institutional vacuum" generate inefficient institutional land tenure systems, promoting land races, land speculation and squeezing, leading to excessive deforestation.

Stabilizing loops correspond to changes in reinforcing loops or new stabilization mechanisms. They generate: a) downward shift of the agricultural land rent curve or b) upward shift in the forest rent curve. In particular, an upward shift in the forest rent curve must be larger than any upward shift in the agricultural land rent curve.

Two of the main results from the FTT are: 1) where there is abundance of forests, there will be (eventually) high deforestation rates and, 2) forests cover eventually will be partly restored. Young (2016) showed that primary forest conservation if more cost-effective than reforestation of degraded areas. Ecosystem services like carbon capture or reduction of soil loss is higher in conserved natural areas than in reforestation/restoration areas.

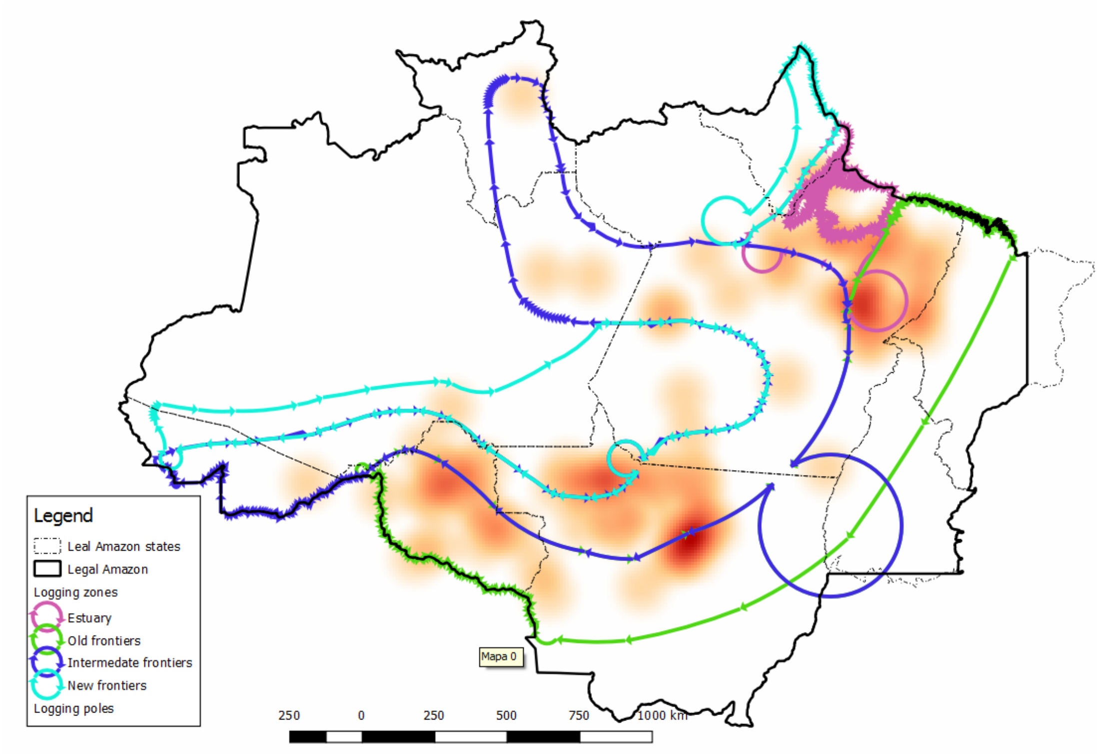
FTT explains forest trend throughout time, but it can also show spatial trends, identifying areas that are at different stages at the same time. Perz and Skole (2003) made an analysis of different studies on non-indigenous settlement histories in different parts of the Brazilian Amazon. They found three types of areas: remote, frontier and settled (see map below).



Map 2: Sub-regions with distinct settlement histories in the Brazilian Amazon.

Source: Perz and Skole (2003).

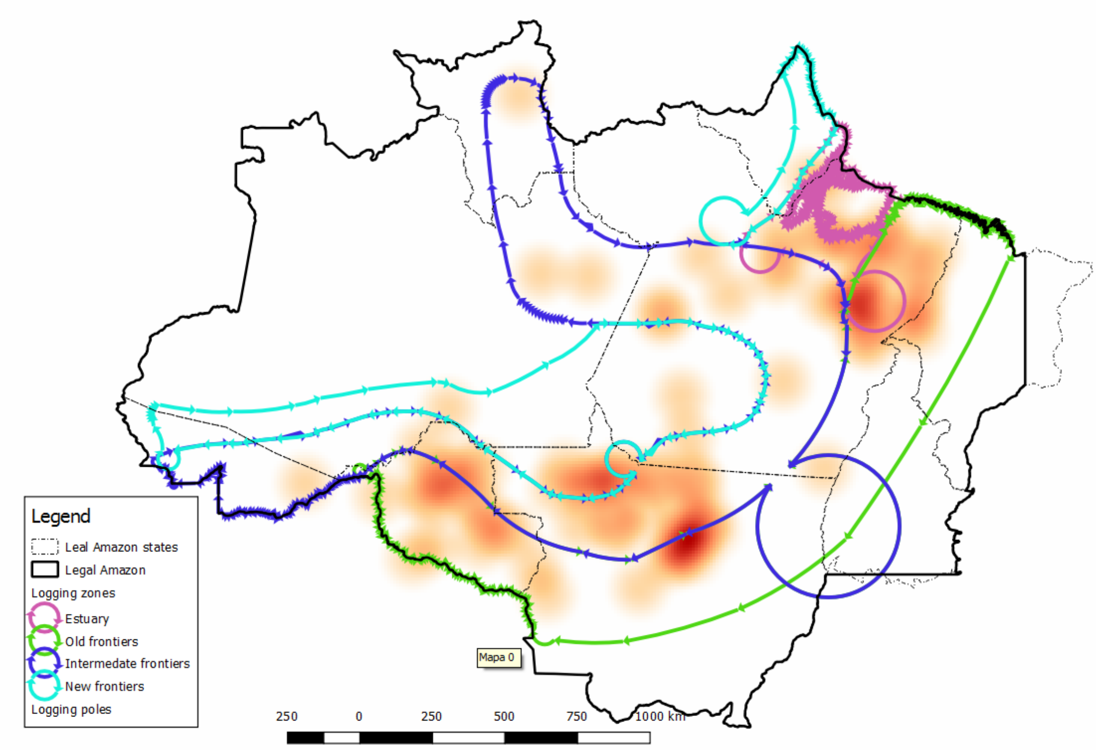
According to Perz and Skole (2003), the settled sub region was first occupied in Brazil's colonial period by Europeans, and has relatively slow growth during the 20th century. The remote sub region had experienced fast land settlements since 1960's, in particular over new roads. Finally, the remote sub region experienced few settlements, in particular over riverine communities and selected areas. These areas represent different points along the FT curve, and show different forest cover and socioeconomic characteristics. Agricultural frontier area is consistent with INPE 's definition of deforestation arc.



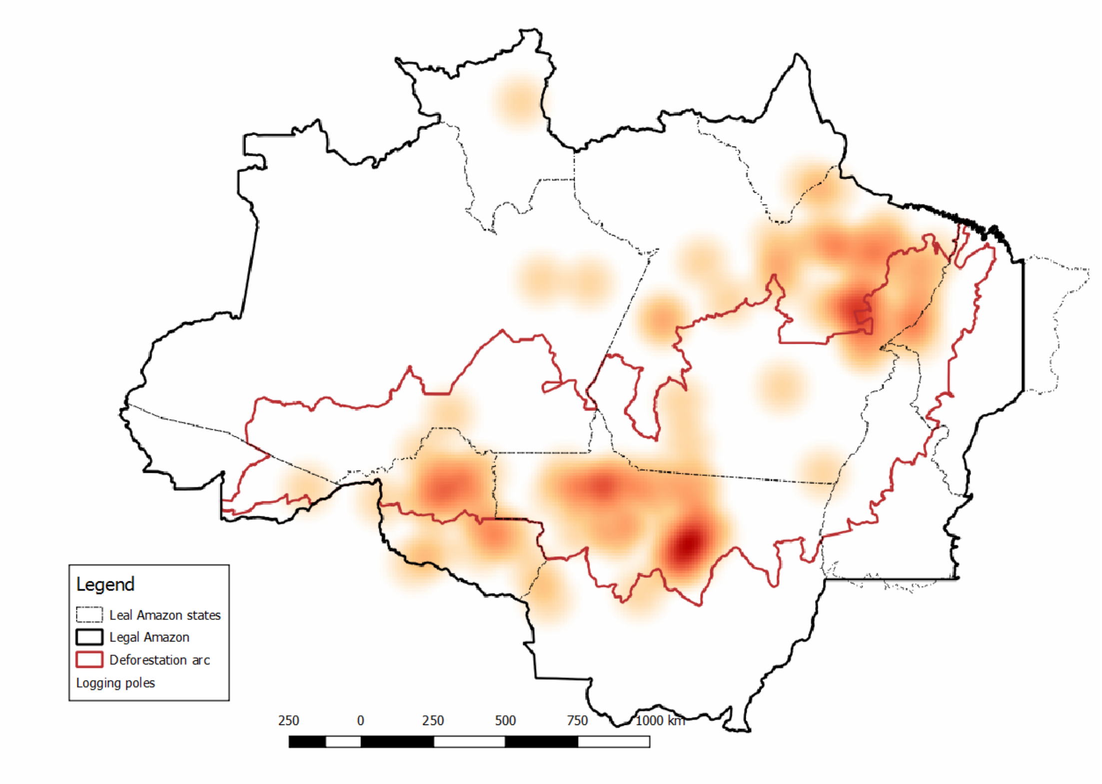
Map 3: Logging frontiers and logging poles

Source: based on INPE and IMAZON GEO.[6]

[6] Imazon is a Brazilian NGO (Non Governamental Organization) focused on environmental conservation and sustainability. They have a geographical tool, called ImazoGEo, that provides information about deforestation and Land use in Brazilian Amazon.

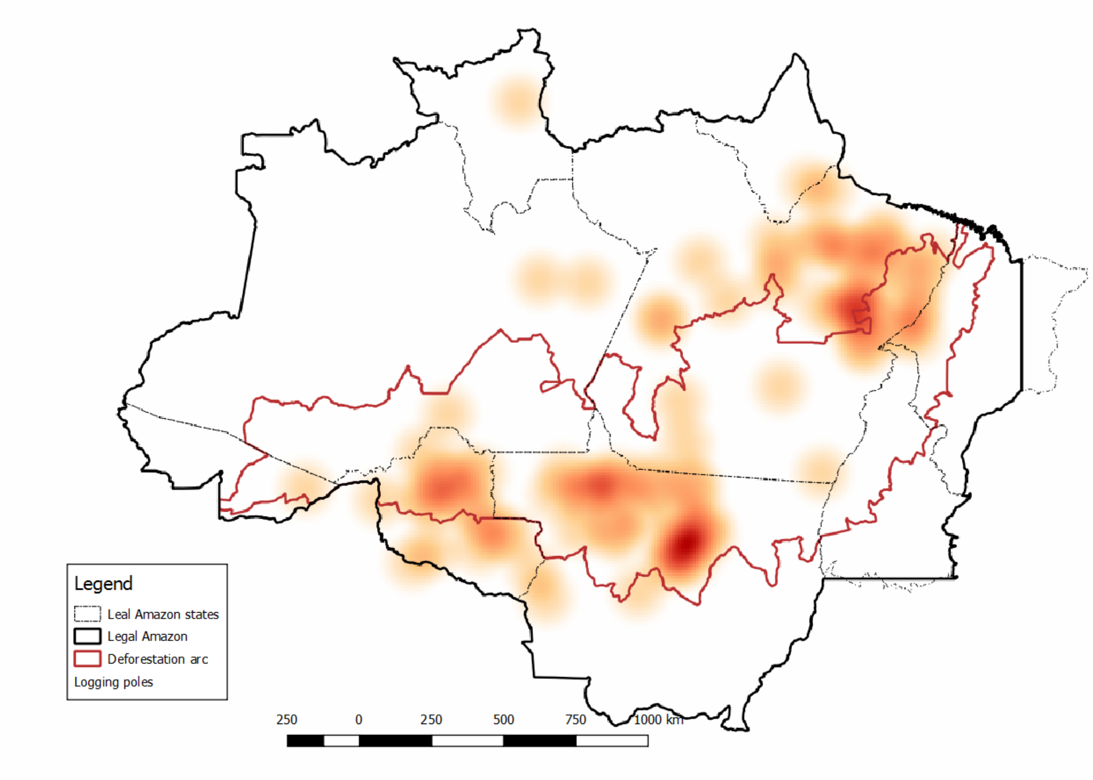


Map 3 show that when logging frontiers are classified according to frontier age and access conditions, and compared with logging poles (in red-orange color), there is an evident correlation between these two variables. As logging poles continue to advance into the Amazon forest, logging zones move upwards, generating an additional pressure over forest remnants. These types of logging zones also correlate with forest transition areas, as proposed by Perz and Skole (2003).



Map 4: Logging poles and deforestation arc.

Source: based on INPE and IMAZONGEO.



Map 4 shows that logging zones and logging poles are also highly correlated with deforestation arc. Most high intensive logging zones are located within deforestation arc boundaries. Moreover, new logging poles that emerge in Roraima and Amazon states, are related with a new deforestation arc area in the northern Legal Amazon.

Forest Transition Theory is associated to some economic models that explain agents' rationality within different phases. Barbier and Tesfaw (2015) showed that forest transition connects two different phases: one in which forest area continuously declining, followed by forest recovery. Initial forest loss is a result of agricultural area expansion, in response to rising demand for food and other commodities, in presence of economic expansion and population growth. As agricultural lands expansion slows down, so does reduction of forestlands. Environmental protection and an increase of demand for wood products and non-market ecosystem services of forestland, leads to a forest area recovery, where plantations and reforestation play an important role.

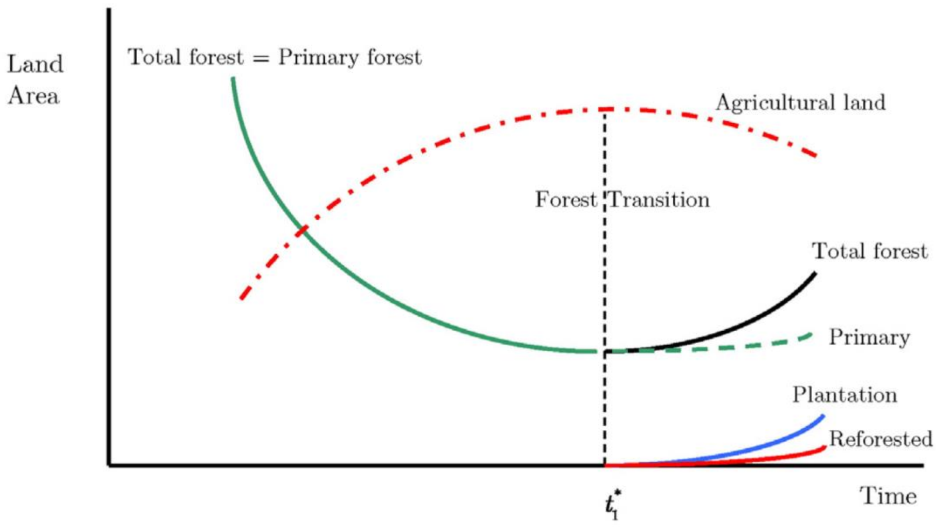


Figure 5: Land use change and forest transition

Source: Barbier and Tesfaw (2015)

Behind these agriculture/forest trade-offs, there is a very important assumption: land is allocated to highest yielding rent the use, and these rents are determined by spatial location from a central market (Angelsen 2007). This is known as the von Thünen model.

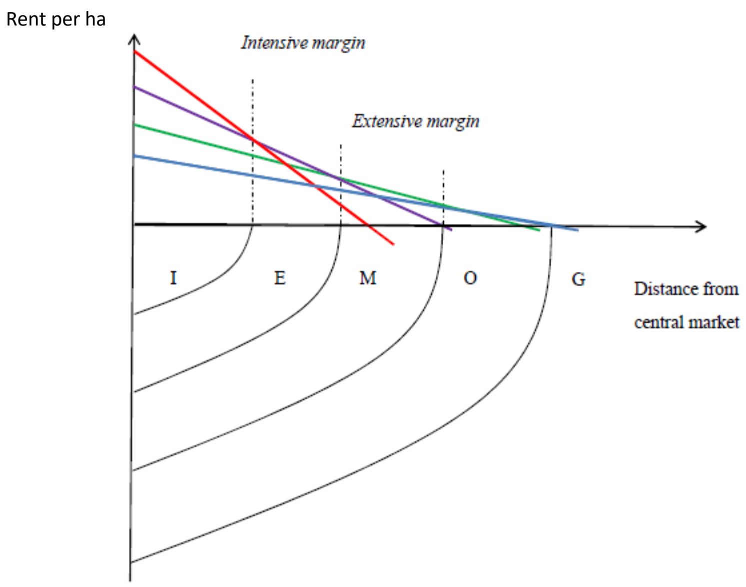


Figure 6: von Thünen model with five different land uses

Source: Robertsen (2011)

I - Intensive agriculture; E - Extensive agriculture; M - Managed forests; O - Open access forests; G- Old growth forest.

Note: The four rent curves are designated by different lines; red = intensive agriculture, purple = extensive agriculture, green= managed forestry, blue= open access forestry.

Figure 6 shows a spatial description of von Thünen model, locating different FTT stages at different distances from the central market as a key variable. This model focuses on how land rent changes for different uses explains changes in land uses and land cover.

Angelsen (2001) developed a mathematical model with five land uses (like forests and agriculture), and showed how to link this model with different FTT stages, land use rents, and how changes in this rents can explain deforestation (see annex 2 for a mathematical explanation of the model and conclusions).

2.2.3 Rationality of peasants at the agricultural frontier: choice of variables from a neoclassical perspective and critique

Agricultural households live in a world of complex relationships inside and outside of their farms. Agricultural household models are a tentative to generate an explanation on how these agents make decisions on time allocation and consumption of goods (LaFave and Thomas, 2012; Taylor and Adelman, 2003). They were first introduced in 1978 to understand the market for staple in Japan (Taylor and Adelman, 2003). Agricultural household models incorporate a firm operated by a family with the household utility maximization problem, in that way, profit maximization on the farm is linked with time allocation of family (household) members and consumption choices (LaFave and Thomas, 2012). The model incorporates a family operated firm into the household utility maximization problem, and links profit maximization on the farm with time allocation of household members and consumption choices. Some of the building blocks of agricultural household models are presented by Taylor and Adelman (2003). Annex 3 presents a summary of main variables included.

LaFave and Thomas (2012) state that: if households behave as if they are price-taking utility maximizers in a world of complete markets, production and consumption decisions may be treated as if they are recursive: in a first stage production choices are made without reference to the household preferences; consumption decisions occur in a second stage taking into account income from farm profits and don't influence back production choices.

Some authors used variations of the agricultural household models including different variations. Angelsen (1999) made an analysis incorporating results of different changes of variables like population, productivity, transport costs and allocation of land titles. Erazo (2001) included forest regeneration and soil fertility as constrains in the maximization problem. Taylor and Adelman (2003) made an analysis on different policies based on comparative statistics, with theoretical or parameterized models. LaFave and Thomas (2012) present an analysis of different household decision like nutrition in farm productivity, agricultural technology adoption, labor supply choices. Angelsen (2001) developed four models to understand deforestation: subsistence, Chayanovian, open economy with private property and open economy with open access. For these models he showed the impact on deforestation as a result of modifications of variables like population, productivity, output prices, transport costs, land tenure security and expectations of future productivity or output prices. Annex 3 summarize these results.

Several authors have analyzed neoclassical rationality as part of agricultural household models. Arrow (1986) showed that for some authors (like John Stuart Mill), a theory of economy must be based on rationality, otherwise there could not be a theory. He also showed that rationality has useful and powerful implications on the presence of other basic economic concepts of neoclassical theory like equilibrium, competition and completeness of markets.

Zafirovsky (2008) finds that economic rationality is an increasingly narrower and simplistic category as economics have moved to a more purist “marginalist-mathematical” direction since the Marginal Revolution (1870). Rationality has also moved from the economic agents´ idea by the classical political economists during the Enlightenment, to hyper-rational fools and unreasonable or automaton–style utility maximizing agents in pure neoclassical economics. This has generated a view of economic actors as simple economic “super-men” driven by utility maximizing, rather than complex human creatures motivated by socio-economic motivations, including morality or economic ethics.

Simon (1979) describe behavior in economics as substantively rational “when it is appropriate to the achievement of given goals within the limits imposed by given conditions and constrains”, therefore, rationality depends on the actor´s goals. “Given this goals, the rational behavior is determined entirely by the characteristics of the environment in which it takes place”. He also showed that classical economic analysis rest on two assumptions: a) economic actors have a particular goal, i.e.: utility maximization or profit maximization; b) economic actors are substantively rational. If these assumptions are unchanged human cognitive processes or human choice from psychological literature are irrelevant. Some other critiques to the neoclassical model are summarized by Tisdell (1996) and Arrow (1986).

The neoclassical view of rationality or substantive rationality had some important critics that lead to a new proposal of rationality. Tisdell (1996) state that, information available to agents is usually limited or distorted then, calculations and thought do impose effective costs and limitations on choice. When thinking about information in a perfect competition environment, Arrow (1986) founds that the optimization problem for each individual based on conjectures about private information that others possess, is clearly more difficult and therefore computationally more demanding, than the optimization problem where there is no private information. An optimal decision on refinement of decisions will be to stop short of gaining perfect knowledge about knowledge that has economic value when additional benefits equals additional costs, but it should be noted that there exists uncertainty about expected net benefits (Tisdell 1996).

Another important critic is that when neoclassical economy is in perfect equilibrium, the expectations of the agents are fully realized, and there is no incentive to review their decisions. Moreover, agents' dissatisfaction with one´s past decision is not sufficient to show that these decisions were rational (Tisdell 1996). Preferences of households making decisions based on the majority rule will not satisfy the transitivity axiom, and aggregation of individual maximizing behavior does not imply maximizing behavior of the aggregate system (van den Bergh et al., 2000).

The neoclassical behavior is based on methodological individualism, which states that all social phenomena can be explained departing from the individual. This view is opposed to the methodological holism, where the whole is not the sum of its parts. In Hodgson´s view, there is no feedback form the system to the individual, it leaves culture and social psychology out of the analysis, instead of understanding the real individual behavior: psychological motivations and processes (van den Bergh et al., 2000). Also, individual experience is not a guide to perfect unbounded rationality; one´s experience may alter one´s preferences, then, individuals' final preferences may depend upon the sequence in which individuals experience things (Tisdell 1996).

Moreover, individual behavior as isolated consumers can´t say much about individuals as political citizens with ethical and social concerns, and don´t take into account that decision making is not isolated form social environment and norms, although they are not the most efficient ones (van den Bergh et al., 2000). If we also think of individual as having homogeneity of the utility function, this can´t explain why alike individuals do not make the same choice, or demise the fundamental assumption of the economy, that is built on gains from trading arising from individual differences (Arrow, 1986).

Herbert Simon made four interesting critics to the neoclassical model of decision making (Kalantari, 2010). First, decision makers cannot be rational unless the decision maker has perfect control on the environmental factors as well as his mental capabilities. Second, there exists limitations on human computational ability and these limitations influence the decision maker´s rational behavior. Third, the decision-maker is considered an observer in the process of decision-making, rather than an actor. Fourth, neoclassical theory ignores limitations that are involved with information gathering to make a decision, like time, costs, organizational culture, to arrive to a decision.

Tisdell (1996) recalls that for Simon, humans, like a computer or a machine, have limited capacities of problem solving. Therefore, Simon calls theories that incorporate constrains on the information processing capacities of the decision maker theories of bounded rationality. The first criticism to neoclassical theory can be then related with unbounded rationality theory, which in turn have no practical or descriptive relevance, as they don´t incorporate the decision maker's limitations. Although Simon does not explicitly oppose to the neoclassical theory, he believed that it can handle behaviors of the economy that relatively stable and are not too distant form the competitive equilibrium (Kalantari, 2010).

Simon (1979) suggests employing the concept of procedural rationality instead of bounded rationality. He states "behavior is procedurally rational when it is the outcome of appropriate deliberation" and it is studied in problem situations in which "the subject must gather information of various kinds and process it in different ways in order to arrive at a reasonable course of action, a solution to the problem". As a result, a theory of rationality is not a theory of best solutions, is a theory of computational procedures to find a good solution or making reasonable choices. It can also be understood as the rationality of a decision in terms of the manner in which it is made (Van den Bergh et al., 2010).

2.2.4 Deforestation from a post-Keynesian perspective

Post-Keynesian theory can help to understand deforestation and land use decisions, from an asset perspective. Alvarenga (2014) show that there is an important difference with neoclassical theory, because it "describes a world where money is neutral, uncertainty can be transformed into a probability – because the economic process is stationary – and the aggregate demand is adjusted through variations in relative prices, conferring stability to full-employment equilibrium”, while post-Keynesian theory “understands that money affects accumulation strategies, uncertainty is an unescapable phenomenon and not calculable from a statistical point of view, and that the principal of effective demand is the element that describes a true relationship between aggregate supply and demand functions”.

The Keynesian theory of assets, gives a perspective on how individuals decide to constitute their assets portfolio, including land. Land acquisition is based on higher expected returns compared to other assets in the economy and expected returns at the end holding period.

Agent's expectations alter prices and land (viewed as an asset) availability, or land speculation, based on two motivations: a) it is a natural agent’s behavior, based on the expectation on accumulation; and b) when expected productivity gains less production and maintenance costs can’t justify, in economic terms, retention of that asset within the portfolio. Then, land retention can be explained when there are agent's expectations on returns from the asset value and a liquidity premium, compared to agent's subjectively calculated prevailing interest rates (Alvarenga, 2014). This perspective allows to overcome neoclassical economic decision-making problems like decreasing land prices while not presenting decreasing productivity and a concept (productivity) that can be seen only when productive phase has ended.

It is important to point out that this model is in a theoretical opposite side from those of Hartwick (1992) and Barbier and Burges (1997). For these neoclassical models, existence of a well-defined property rights regimen is a necessary condition for the optimal control model to achieve an optimal vector price within a market for agricultural lands (or forests or deforestation), that will guarantee an efficient resource (forest land) use. For the Legal Amazon case, this does not happen, because property rights are established after deforestation has occurred and later development of an agricultural activity; then, optimal prices is not the mechanism to achieve optimal deforestation (Alvarenga, 2014).

2.2.4.1 Income definition

Income is a basic definition form the Keynesian point of view: it departs from the neoclassical assumption of resources' full-employment, and it is not defined *a priori*. Instead, definition of effective demand and user cost allows to identify individual decisions concerning alternative ways of keeping assets (Young, 2013), and aggregation of individual decisions can identify society’s income (Alvarenga, 2014). According to this view, “the entrepreneur's income from any productive activity (E) in a time period t is defined as the difference between the revenues obtained from the sale of final goods (A), and the user cost (U) and the amount paid for other production factors - labour, capital - (F) involved in the production" (Young, 2013). Then income from the entrepreneur's perspective can be defined as:

Equation 1: Keynes' entrepreneur income

$$E = A - F - U$$

User cost (U) is the measure of sacrifice that the entrepreneur is willing-to-accept when producing final goods (A) instead from leaving it unused. It incorporates current expenditures on non-labour intermediate inputs and expected losses in the asset stock due to production.

User costs has two components (Alvarenga, 2014): a) if the entrepreneur uses its asset (forest land) to produce a final good (A); and b) if the entrepreneur doesn't use its assets. In the first case, G represents the value of the assets' stock after production of a final good (A). G is the result of the entrepreneur's effort to enhance and preserve its capital assets, through its own effort or from purchases from other producers (A_1), and depreciation for use of the assets (land in this case) when using them in the production process. Then, (G-A_1) is a measure of the asset's stock sacrifice to produce the final good (A). Alternatively, G' can be defined as the value of non-used assets' stock at the end of the production period, and B' are the improvement and maintenance costs to achieve G'. Then, (G'-B') is the asset value when not used to produce the final good (A). The user cost can be expressed as follows:

Equation 2: Keynes' user cost for used and non-used assets

$$U = (G' - B') - (G - A_1)$$

Then it is possible to understand entrepreneur's income in terms of user cost definition. It is useful to identify two types of income: current income (E_1) and capital income (E_2).

Equation 3: Income definition, including user cost (current and capital income)

$$E = A - F - [(G' - B') - (G - A_1)]$$

Equation 4: Current income

$$E_1 = A - F - A_1$$

Equation 5: Capital income

$$E_2 = G - (G' - B')$$

These two components show that maximizing entrepreneur's income implies a decision on current gains and losses over present production levels and sales, and expectations on sacrificed future gains and losses on asset's stock value used for current production (Alvarenga, 2014). Deciding the scale of production, the entrepreneur is also deciding how much of the capital stock will be preserved, then a proper calculation on income maximization, should include long-term consequences of existing stock assets (Young, 2013). This last component is introduced through the use of the user cost concept. Uncertainty about future value of the asset is also part of the user cost concept, then in the absence of property rights, the capital component is irrelevant in production decision. This extreme case, can be related to slash-and-burn scenario, and is fundamental to understand deforestation from a theoretical point of view.

2.2.4.2 Basic model: slash-and-burn with undefined property rights

The basic model to analyze deforestations is based on Young (1996; 2013) and later developments by Alvarenga (2014). The objective of this model is "not to determine an optimal set of prices which would assure the most efficient use of the resource, but to examine how forest clearing decisions are affected by a set of policy-related variables in the context of imperfect markets and uncertainty, where prices are given and expectations have exogenous elements in their formation" (Young, 2013). It also allows to avoid a hypothetical but non-existent social central planner and agent's utility maximization, because Keynesian model is based on profit maximization of individuals, according their expectations, and recognizes theoretically market imperfections and speculative behavior of frontier economies (Young, 2013), in a more consistent way to actual Legal Amazon conditions. This model can also be viewed as an alternative to Tisdell (1996) and Arrow (1986) critique to neoclassical rationality, and closer to Simon (1979) and Van den Bergh et al. (2010) rationality proposal.

This model assumes property rights are not defined before land clearing as in a slash-and-burn subsistence cultivation. Most important features are (Young, 1996; 2013):

- There is no consideration of capital accumulation, and only the current component is relevant
- Slash-and-burn has a low productivity per unit of area, as there is no investment,

- Labour and transportation costs are the only relevant costs
- There is no payment of interests, or transfers like direct subsidies, taxes, etc.
- Farmers are price takers for products and for wages, that is production at the frontier is small and cannot affect agricultural markets prices, that are determined by policies and market conditions outside the frontier region.
- Forested land is not homogenous, then first cleared area is expected to have higher net returns[7]. As a consequence, agricultural revenues per unit of land decrease if more land is cleared, but labour and transportation costs increase.
- Productivity and profitability decrease with expansion of deforestation (cleared area)

Previous characteristic can be summarized in equation 6.

Equation 6: Entrepreneur's income with undefined property rights

$$E1 = A - C = A - W - R$$

$$A = (\bar{p}_a * q_a)$$

$$W = (\bar{p}_w * q_w)$$

$$R = (\bar{p}_r * q_r)$$

Where, A is total revenue of agricultural production, C is total production costs (labor costs plus transportation costs), W is labour costs, R is transportation costs, q_a, q_w and q_r corresponds to total agricultural output, quantity of labor used and quantity of transportation required. Finally, $\bar{p}_a$, $\bar{p}_w$ and $\bar{p}_r$ area exogenous prices for agricultural product, wages and transportation cost respectively. Factor productivity is given by the following equations (Alvarenga, 2014):

Equation 7: First and second order conditions for entrepreneur's income in relation to deforested area

$$\frac{dE}{dL} > 0; \frac{d^2E}{dL^2} < 0$$

[7] For example, land plots that are near roads present higher returns. Then, deforestation starts in forest areas closer areas to roads, and will continue with adjacent plots to cleared land, that are further away from roads.

$$\frac{dq_w}{dL} > 0;\ \frac{d^2q_w}{dL^2} \geq 0$$

$$\frac{dq_r}{dL} > 0;\ \frac{d^2q_r}{dL^2} > 0$$

The first equations show that final good productivity declines with the expansion of deforested area, but with decreasing returns to scale. The second and third equations show that cost increase at a positive rate (increasing marginal costs), once there is more deforested land incorporated to the market. Second equation show that increase on the labour demand has a non-strict concavity, therefore, labour demand can grow at proportional or more than proportional rates compared to additional units of deforested land.

If there are not established property rights, the decision on how much land to clear is based only on the maximization of the current component: land will be cleared up to where current costs exceed total current revenues. New agricultural land supply price doesn't incorporate loss of stock for goods and environmental services (Alvarenga, 2014) or depletion cost (Young, 1997; 2013). This generates and additional incentive for additional deforestation (see Figure 7)

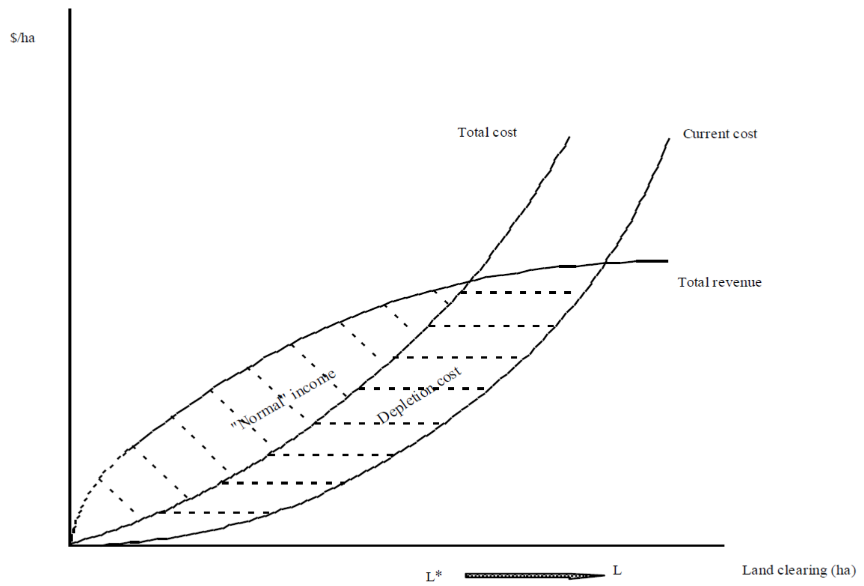


Figure 7: Income maximization in the slash-and-burn scenario

Source: Young (1996; 2013).

Vertical axis in Figure 7 represents income and costs from deforestation and agriculture activities. Horizontal axis represents the amount of deforestation or land cleared for agriculture. Income is maximized where total income equals costs (total costs or current costs), and a total of land clearing (L) for agricultural use. L represents a quantity of deforestation decided without incorporating capital costs. I such costs were incorporated, total costs would be higher, and with an associated amount of deforestation (land cleared area) equal to L*. Excess deforestation for not incorporating property rights is L-L*. In addition, the difference between income associated with maximizing only current costs and that associated with "normal" income, incorporating capital costs and current costs, is de depletion cost (Young 1996, 2013), revealing the lost value of environmental goods and services (Alvarenga, 2014) associated to cleared forest areas. Absence of land titling, implies that a spot land market is inexistent, and that there is not a premium for selling the asset (equity gains), or a liquidity premium.

Short run decision making implies that there is no investment or efforts to enhance and preserve its capital assets, as a consequence, soil fertility declines up to levels that are not economically viable. Anon (1998) show this situation when slash-and-burn is combined with cash crops and extensive cattle ranching (see Annex 5). Slash-and-burn, in the agricultural frontier, increases natural low soil fertility of cleared land by releasing nutrients contained into forest biomass. New higher fertility levels can support cash crops or traditional pastures management. Once fertility is not adequate for cash crops, traditional pasture is developed until soil fertility lies below natural fertility levels, generating land degradation. Degradation is a consequence of lack of investments to preserve the asset (agricultural land) characteristics (fertility), that is, there is not investment on fertilizers or other activities[8] to replenish fertility levels to at least natural fertility levels. As a result, agents discards the property and looks for another primary forest plot to clear, or other plots let to rest for a long period, with secondary vegetation (capoeira), with enough biomass to allow a new cultivation cycle with lower clearing costs compared to primary forests (Young 2013). Slash-and burn systems self-perpetuate, discouraging landholders from making fire-sensitive investments in their land, and not allowing them to move beyond their dependence upon fire as a management tool (Nepstad et al. 2001).

Table 1: Economic policies' effect on deforestation with undefined property rights

Variable to modify	Effects on revenues and costs	Effect on deforestation
Higher agricultural prices	Upward shift in revenue curve	Increase
Lower labor costs	Downward shift of current cost curve	Increase
Decreasing transportation costs	Downward shift of current cost curve	Increase

[8] Some activities to recover soil fertility are live coverings with nitrogen fixing forages, establishment of live fences, dispersed trees on pastures, pastures with rational management, or establishment of silvopastoral systems. All these systems imply important investments for the agricultural producer.

Source: adapted from Young (2013).

Different changes of variables like agricultural prices, labor and transportation costs, have result on deforestation as the ones found in the literature as immediate causes of deforestation.

2.2.4.3 Introduction of selling rights and interactions between old and new frontier

In a scenario of quasi-open access land, property rights are established after land is occupied, through agricultural activities. Deforestation is motivated by expected profits from land accumulation, and property rights are claimed once deforestation occurred (Young, 1997; 2013). Some main characteristics are:

- Capital component includes gains from selling the land, net timber and other natural resources that existed prior to deforestation.
- Capital gains arise for the settler by introducing “new” land into the land market.
- The value of asset stocks own by the settler (G in the income definition), increases rather than decreases after its use.
- There is a capital appreciation since the value of the asset stock, or cleared land (G), is greater than value of the assets' stock after production (G’) of final good (A), or agricultural activity.
- Land appreciation corresponds to the capital gain minus the cost of the sacrifice of depleting the forest, or forgone environmental goods and services, generating a quasi-rent.
- Settler claims plots of areas larger than deforested areas to incorporate a forest reserve within the farm.
- Deforestation can occur inside the property, in forest reserves in the farm or outside the property, in areas that have not yet been claimed as private property.
- Natural resources, that is forest lands, are inputs to produce land property rights. Then, demand for land clearing reflects expectations on quasi-rents, capital gains from selling the land (equity gains) once property rights are granted, and liquidity premium, incorporated in the discount rate that brings to present value future expected income.
- Late settler has access to credit and higher capital endowment then, his expected net present value of income per hectare is higher than early settler’s current income. The later implies that late settler’s demand price for land is higher than early settler’s demand

price for that asset, or alternatively, late settler's willingness to pay for a defined land is higher than early settler's minimum willingness to accept to that same land (Alvaernga, 2014).

The possibility of transferring land property in exchange for a monetary compensation give rise of a new agent: a latte settler or second generation agriculture, that inhabits the old frontier. Late settler will buy land from an early settler or *colono*, that inhabits the new frontier, up to the point where expected return equals the cost of intensifying production in the land already owned by the late settler (Young, 2013). This duality between late settler (old frontier) and early settler (new frontier) can be describe by the following characteristics.

- Early settlers land demand is motivated by expected capital gains, that is, gains from selling land (equity gains), liquidity premium and very fast cleared land price appraisal.
- They are located in the new frontier where property rights are not defined yet.
- Considering that they maximize only current income, short run is their planning horizon, then, showing low capital investment levels and showing low lands' productivity.
- Late settlers inhabit the old frontier after definition of property rights
- They are also subject to decreasing returns to scale in production and increasing costs per unit of area (marginal costs).
- Land demand is motivated by excess of quasi-rents over maintenance cost, that is, net income of agricultural products' sales.
- With property rights established, late settlers make investments to preserve the asset stock value. This includes: machinery and equipment, fertilizers, among others.
- Current costs include payment of interest rates because late settlers have access to credits.
- Capital costs include depletion of natural resources in the estimation of future revenues and costs.
- Late settlers don't speculate with land prices, then expected net present value of net revenues from agricultural production reflect capital losses and gains.

Late settlers incorporate the depletion cost and not the early settlers. In one hand, in the new frontier there is no definition of property rights, and hence, early settlers (*colonos*) don't incorporate capital costs, which include depletion costs. In the other hand, late settlers, acquire lands with forest resources, then depletion costs are associated to forest lands that exist within a delimited and legalized property, and not in deforested areas within the new frontier (Alvarenga, 2014). Then latte settler income can be expressed by Equation 8 and Equation 9.

Equation 8: Late settler's income

$$E_L = NPV(\, A_L - C_L) = \sum_{t=0}^{\infty} \frac{(\, A_{L_t} - C_{L_t})}{(1+d)^t}$$

Equation 9: First and second order conditions for late settler's income in relation to deforested area

$$\frac{dA_L}{dL} > 0; \; \frac{d^2A_L}{dL^2} < 0$$

$$\frac{dC_L}{dL} > 0; \; \frac{d^2C_L}{dL^2} > 0$$

Again, we can see that late settlers face marginal returns to scale for agricultural production for each additional plot of cleared land. Also, they face increasing transportation and labour costs.

Demand for legalized (registered) lands is a result from the introduction of late settlers in the old frontier. This generates expectations on future income for early settlers in the new frontier. This expected income enters early settler's income as follows:

Equation 10: Early settler's income

$$E_E = \; A_E - C_E + \; \alpha * p_{l_L}$$

$$p_{l_E} = \; \alpha * p_{l_L} \quad ; \quad 0 < \alpha < 1$$

Equation 11: First and second order conditions for early settler's income in relation to deforested area

$$\frac{dA_E}{dL} > 0; \; \frac{d^2A_E}{dL^2} < 0$$

$$\frac{dC_E}{dL} > 0; \; \frac{d^2C_E}{dL^2} > 0$$

Income from cleared land sold to a late settler, capital gain, corresponds to $p_{l_E} = \; \alpha * p_{l_L}$, which represents land price for the early settler in the new frontier. It also represents a fraction (α) of the land price in the late settler land market. This fraction is a subjective value calculated by the early settler and represents the expected degree of confidence on obtaining a land title once deforestation has occurred on cleared land on the new frontier. On the extreme case of α=0, lack of security over property rights will prevent any transaction. If α=1, there is no incentive for the late settler to buy land because he would find equal quality land with lower transportation costs in the old frontier, as investment on the infrastructure in the new frontier tends to be lower.

Deforestation for an early settler is explained on future income expectations from selling the land, even if the net revenues from agricultural activities are low or negative, given a technology and capital. The latter is the base for land speculation (Alvarenga, 2014). Land clearing (deforestation) will go up to where marginal costs equals current marginal revenues plus expected capital gains. Early settler deforestation is higher than in the slash-and-burn scenario, because, income maximization considers only revenue component, while in quasi-open scenario considers current and capital components. The logic of developing agricultural activities with low or negative revenues is straightforward, "the 'appearance' of using the land for production, endorses the claim for property rights" (Young, 2013). This relation between old frontier and the new frontier is depicted in Figure 8. Top right quadrant shows the situation in the old frontier. E'(ls) corresponds to marginal income curve for the late settler, and maximum deforestation in the region (L(of)), is located at the point where net present value of marginal income from land clearing equals zero. This occurs because property rights are well defined in the old frontier. Also marginal income curve determines land prices in the old frontier ((pl(of)). Top left quadrant shows that land price in the new frontier (pl(nf)) is a fraction (α) of land price in the old frontier (pl(of)). Bottom left quadrant shows the new frontier. Marginal income curve for an early settler (E'(es)) equals the sum of marginal current income (El'(es)), that is a marginal current income from current agricultural land use, and expected capital gains (pl(nf)) from selling land. Introduction of property rights implies that deforestation in the new frontier is higher (L(nf)) than slash and burn (or open access) scenario (L*(nf)), since there is an additional incentive from capital gains.

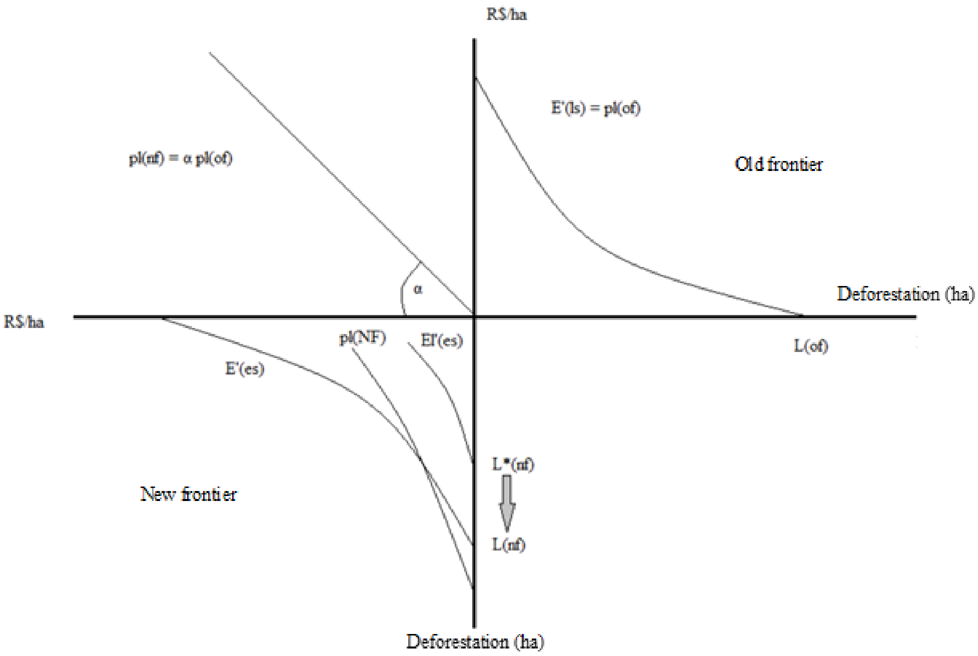


Figure 8: Duality at the frontier: new and old frontiers.

Source: adapted from Alvarenga (2014).

Young (1997; 2013) model has a powerful characteristic: it shows how conditions on the old frontier affect land use decision making on the new frontier, that is the indirect effect of deforestation. For example, a new road in the old frontier increases net present value of expected income, because for the same land it will be expected higher return. Then, marginal income curve for the late settler increases (rightward shift). This implies a higher demand land price in the old frontier, and also an increase in the new frontier land prices. Increase of new frontier land prices, implies an increase on expected capital gains (leftward shift of pl(nf)), and generating and increase on the marginal income for late settler (leftward shift of E'(es)). The result is an increase of deforestation in the new frontier.

Table 2: Government policies' impact on deforestation in new and old frontier.

Change in variable	Effect on			
	old frontier (marginal income)	land prices	new frontier	deforestation
+ agricultural prices - production costs	+ E'(ls) rightward shift	+ new frontier (pl(nf)) and old frontier (pl(of)) simultaneously	+ capital gain (αpl(of) leftward shift) + marginal current income (El'(es) leftward shift) +marginal income (E'(es) leftward shift)	+ L(of) + L(nf)
+ new (improved) road in old frontier	+ E'(ls) rightward shift	+ old frontier (pl(of)) first, + new frontier (pl(nf)), later	+ capital gain (αpl(of) leftward shift) +marginal income (E'(es) leftward shift)	+ L(of) + L(nf)

+tax on land transfer, ban on re-selling	Not effect	- new frontier (pl(nf))	- capital gain (αpl(of) rightward shift) - marginal income (E'(es) rightward shift)	- L(nf)

Source: own elaboration based on Young (2013).

Government policies have and indirect effect on deforestation. Table 2 summarizes the effects of changes of different variables on the new and old frontiers. An increase of agricultural prices, has a direct effect on the marginal income in the old frontier, increasing also land prices in both frontiers and generating an increase in early settler's marginal costs (affecting marginal current income and capital gains, as well). As a result, deforestation increases in both frontiers. If there is a policy to improve roads in the old frontier, late settlers' marginal net income increases, as transportation costs decrease; this generates an increase first in old frontier land prices and later an increase in new frontier land prices (as they are related), and marginal income for early settler increases, as a result of an increase only on capital gains from land sales. At the end, land clearing expands in both frontiers. This last scenario shows the multiplier effect of land price speculation on deforestation.

Finally, some government policies that can help to reduce deforestation are taxes on land transfers, stopping land concessions to large farmers, ban on re-selling land distributed to small farmers, better control against encroachment on public and indigenous territories, or reducing the uncertainty on capital markets, creating a safe alternative to investment in real assets such as land. These policies reduce expected income from deforested land sales, reducing deforestation profitability (Young, 2013).

A final consideration can be made: if there is an income increase for the late settler, it is possible that additional deforestation occurs in the new frontier. Considering late settlers as a risk averse agents, it is possible that additional income be invested in previously owned land to increase productivity rather than buying non-regularized new agricultural lands in the new frontier. In addition, if the 'speculation multiplier' effect is controlled through adequate policies, that is, there is a decouple of land prices between old and new frontiers, then agricultural land demand in the new frontier is inversely related to intensification costs in the old frontier.

2.3 Payment for environmental (ecosystem) services

2.3.1 PES definition

Promotion and protection of ecosystem services and reduction of their threats is possible through economic incentives as an instrument that supports this task. Economic incentives seek to modify institutional and individual behavior to achieve an integrated or partial conservation and sustainable use of biological diversity, and the fair and equitable sharing of the benefits derived from the use of genetic resources, which are part of the Convention on Biological Diversity. Biological Diversity (SCDB, 2004). In addition, economic incentives can modify the behavior and decisions of different actors to reduce future risks in the natural system and the social costs associated with the irreversibility of ecosystem transformation. Thus, it is possible to balance the short-term private costs or benefits related to the use of biodiversity and the medium or long-term social costs or benefits from this use (IAvH, 1999).

Börner and Vosti (2013) show that the lack of provision of ecosystem services, and their excessive use or lack of investment for their protection are associated with the fact that the value of these services is not perceived, captured or not evident by the individuals who are in charge of their provision. To put in other words, only the social cost is perceived. These same authors propose that governments and local beneficiaries of ecosystem services provide direct incentives that promote land use practices that provide additional services or that promote the conservation of these services.

There is a wide variety of mechanisms to promote the conservation and sustainable use of biodiversity, classified according to how they attempt to change people's behavior (Börner and Vosti 2013). Figure 9 shows there are 3 types of ES management instruments (Börner and Vosti, 2013):

a) Enabling: establishment of general conditions that allow incentive-driven behavior to contribute to the achievement of a specific ecosystem service objective. They include a transfer of property rights, technology upgrading, environmental education, partnerships (e.g. public-private partnerships), credit and insurance.

b) Incentives: provision of (specific) incentives that change behavior in ways that contribute to the achievement of a particular objective in relation to ecosystem services. They include payments for environmental services, subsidies, provision of inputs, tax exemption, and certifications.

c) Disincentives: provision of (specific) disincentives that change behavior in ways that contribute to the achievement of a particular ecosystem service objective. They include taxes (user fees), regulations (bans, standards) and fines, refundable deposit schemes.

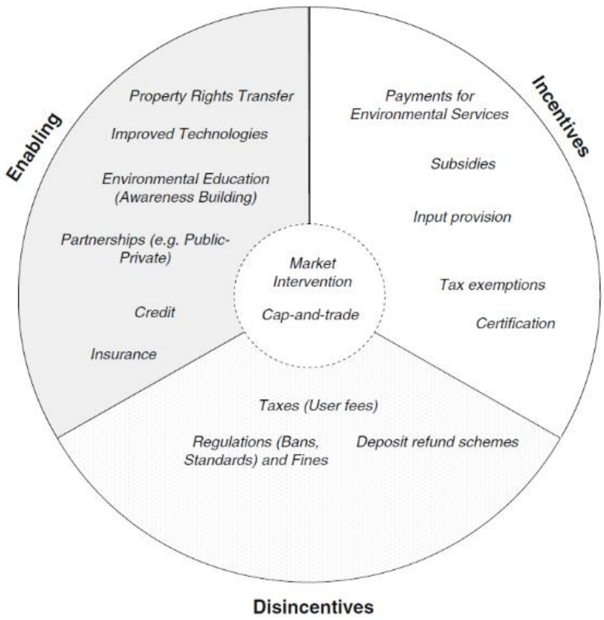


Figure 9: Ecosystem services management instruments by means of impact

Source: Börner and Vosti (2013)

Young and de Bakker (2014) state that "the use of economic instruments is important to provide a flexibility to comply with environmental targets, as a complementary tool to the command-and-control approach. It is in this context that payments for environmental services arise as one of the incentives that support the provision and maintenance of ecosystem services. However, what does ecosystem service mean? For Wunder (2015) payments for environmental services (PES) can be defined as:

(1) voluntary transactions

(2) between service users

(3) and service providers

(4) that are conditional on agreed rules of natural resource management

(5) for generating off-site services.

The structure of the PES scheme has a logic represented in Figure 10. That figure shows that in a conventional initial situation, there is a land use that reduces the provision of environmental services such as reduction of water services, loss of biodiversity or generation of greenhouse gas emissions. This activity has a profitability (net income) associated with the landowner. By generating a change of land use, towards an activity that reduces the loss of environmental services, it is possible to reduce the profitability for the landowner who is the supplier of environmental services. If the reduction in profitability is less than the gain in environmental services, then the development of the new alternative will be desirable from a social perspective. In this context, Engel (2016) proposes that the PES mechanism transfer part of the increases in environmental services that the beneficiaries of this increase perceive to the service providers (landowners), so that the total benefits of the activities that are desirable from a social perspective are greater than the benefits of conventional activities.

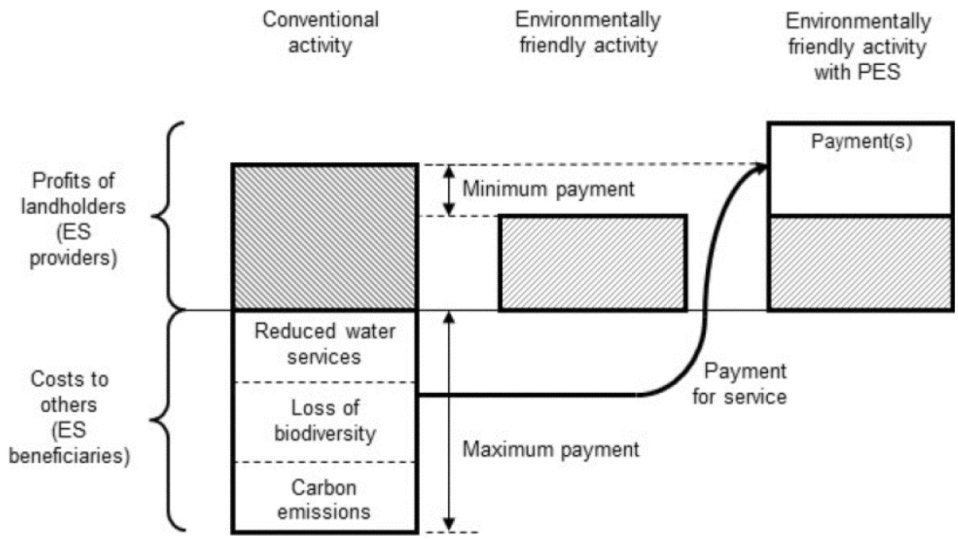


Figure 10: Logic of PES

Source: Engel (2016)

We can conclude that a PES system has a simple logic: the ES user pays to the provider or protector, to increase income from conservation activities to promote sustainable use of natural resources, while penalizing predatory activities, and incentivizing conservation of goods and services freely provided by the environment, but of direct or indirect interest to human beings (Young and de Bakker, 2014).

2.3.2 Opportunity costs

Young et al. (2007) proposed that land owners in the agriculture frontier are rational economic agents that tray to maximize income from their properties. Then, the decision on land use is equivalent to a portfolio composition: forested land is a financial asset that will have a higher probability of being cleared, if agriculture or cattle ranching uses are more profitable. In that context, opportunity costs for conservation can be understand as the maximum profitability that land owners expect from forest land in the case he converts it to a more lucrative use like agriculture or cattle ranching (Young, Mac-Knight and Meireles 2007; Pagiola and Bosquet 2009, Mota et al. 2010). It is important to keep in mind that the opportunity costs of REDD are not given by the value of the benefits foregone from the alternative land use, but by the difference in net benefits between forest and the alternative land use (Pagiola and Bosquet 2009, Börner et al 2010).

Opportunity costs can also be determined when use costs for certain activities do not have a defined market price. In this case, opportunity costs are defined as a proxy of forgone income, for not using a resource in other alternative uses that do have a market price (Izko and Burneo, 2003). Some limitations of this methodology are: 1) it can't be used as an appropriate value for compensating ecological damages (Izko and Burneo, 2003); 2) the result should be seen as an approximation for the minimum value of a defined benefit (Izko and Burneo, 2003); 3) cost-effective and precise estimation of site specific opportunity costs is a major challenge, and for some cases annual land rents or models regressing opportunity costs on spatial and socio-economic independent variables appear to be a well estimator (Wünscher& Engel, 2011; Wunder, 2011).

Opportunity costs are not the only cost in conservation projects (in particular REDD projects), they are also part of overall conservation costs, which include implementation costs and transaction costs, and in some cases, opportunity costs are the lowest costs, compared to other implementation costs (Izko and Burneo, 2003; Olsen and Bishop, 2009; Taconi, Mahanty and Suich, 2010).

Börner and Wunder (2008) and Wunder and Börner (2013) showed that opportunity costs of deforestation imply multiple and sequential land uses over time (Figure 11). One of the first activities that are being developed is wood extraction. This process starts by harvesting fine or hard woods, which have high commercial value. Later, some subsistence crops are established and then, remaining forest is clear-cut or burn to establish extensive cattle ranching, or other commercial crops like soybean. The system continues by developing a series of different production systems over a 10-year period.

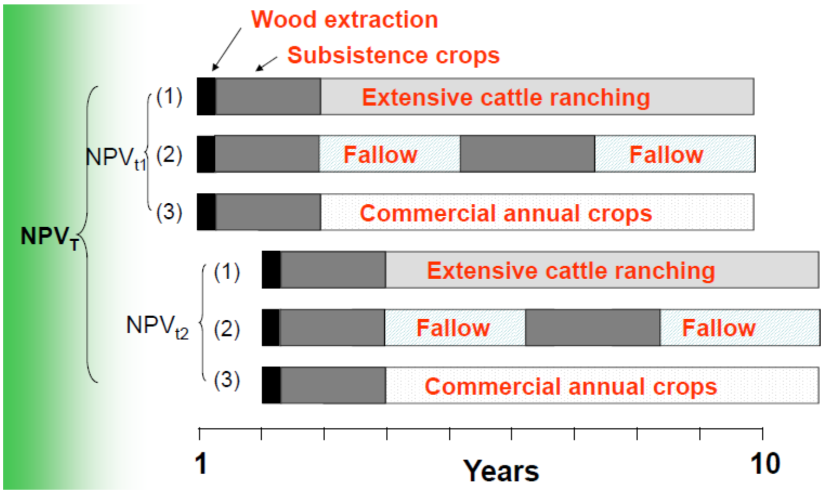


Figure 11: Stylized land clearing trajectories, used for opportunity-cost estimations

Source: Wunder and Börner (2013), Börner and Wunder (2008)

Börner et al (2010) used the land clearing trajectory methodology and made some estimates of average share of different agriculture and cattle ranching activities. Table 3 shows that cattle ranching accounts for 80% of land use expansion in Legal Amazon, followed by permanent annual crops like soybeans.

Table 3: Average share and net present value (NPV) for major land-use trajectories in the Brazilian Amazon.

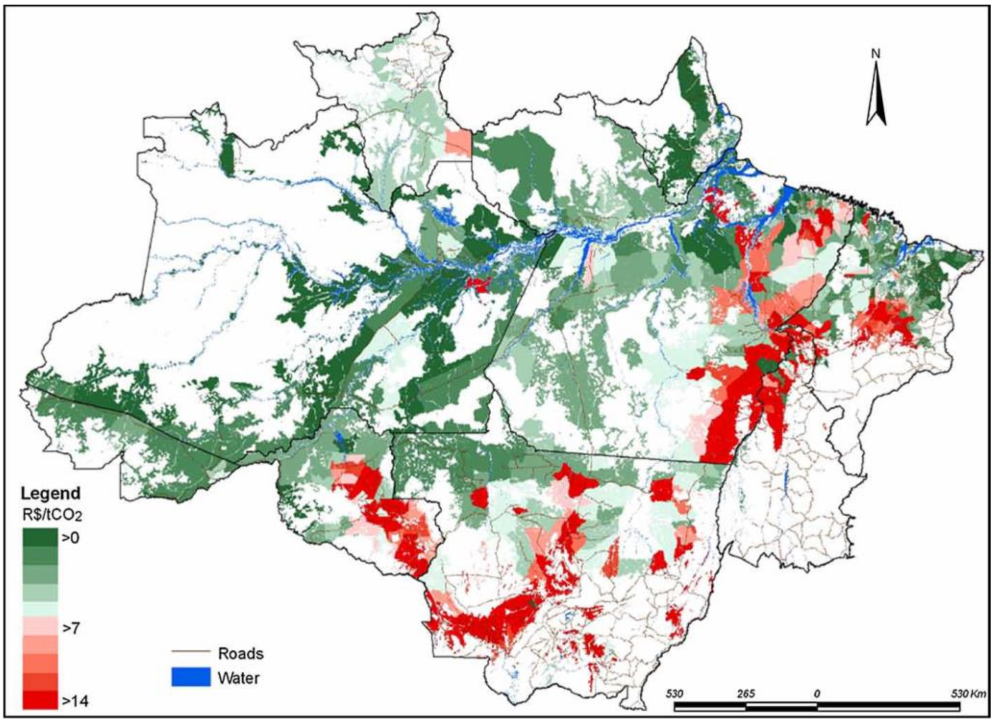
Land-use trajectory	Average share in land-use expansion [% of expanding land uses]	Average NPV[a] [R$[b] per hectare]
Pasture	79%	$1661.77
Fallow-based annual cropping	6%	$1615.08
Permanent annual cropping (soybeans)	12%	$2358.56
Perennial cash-crops	2%	$6603.04

[a] Time horizon of $T = 10$ years and 10% discount rate.
[b] US$1 = R$2.2; 10.2008.

Source: Börner et al (2010)

Like other studies, the lowest opportunity cost is related with cattle ranching (only exceeded by fallow annual crops, but with very low participation). While livestock production continues to be one of the most important land uses after deforestation, other land uses, if taken into account, can increase opportunity costs. If we use Erazo (2014b) approach to calculated expected opportunity costs, multiplying each average NPV times the average area share of each land use and then add them up, then the expected opportunity cost is R$ 1.824,79. Following the same approach, Wunder et al. (2008) showed that including opportunity cost for other crops that have higher net income can increase the opportunity costs.

Map 5 shows that for a price of a temporary carbon offset, 81% of the areas will be suitable for REDD+ activities. Areas with lowest opportunity cost are in Amazonas, Acre and Amapá (high biomass, low accessibility), while uncompetitive areas are located near highways, cities, present high timber values or low biomass.



Map 5: Opportunity cost for REDD in deforestation threatened areas up to 2050.

Source: Soares-Filho et al. 2006, IBGE-PAM/PPM/PEV 2000-2006, cited by Börner et al (2010)

Note: Green areas = competitive REDD areas; red areas = excessive opportunity cost for REDD.

Figure 12 shows that approximately 12.5 million hectares of projected deforestation are avoided with an average price of R$6,8 /$tCO_2$ (USD$2,81), to temporarily reduce emissions.

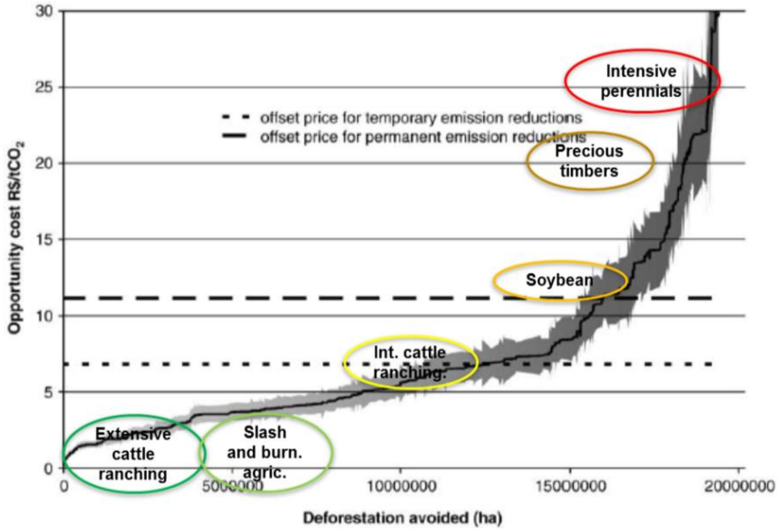


Figure 12: Avoided deforestation cost curves with offset price for temporal and permanent emissions reductions.

Source: adapted from Börner et al (2010).

Lowest opportunity costs are related with extensive cattle ranching and slash and burning agriculture (relevant as R$1 /t$CO_2$ or USD$0,45), while soybean is relevant around R$11,16/t$CO_2$ (USD$5,07). Extraction of high value timber and intensive perennials can be compensated with a carbon rice of $R 20 /t$CO_2$ (USD$9,09) or higher prices. When land tenure issues are incorporated, less than 25%[9] of the area is eligible, corresponding to sustainable use protected areas, indigenous preserves, and partly in individual farms and communal lands. May, Millikan and Gebara (2011), found that only 4% of titles in the Brazilian Amazon correspond to private property validated by INCRA, while 32% correspond to private lands without validation.

Another study by Duchelle et al (2013) in four REDD+ project sites within the Legal Amazon showed some additional information (Table 4).

Table 4: Comparative characteristics and strategies of four sub-national REDD+ pilot initiatives studied

	SISA, Acre	Sustainable settlements in the Amazon, Transamazon highway region, Pará	Central Xingu REDD+ Pilot Program—São Félix do Xingu, Pará	Northwest Mato Grosso Pilot REDD+ Project—Cotriguaçu

[9]67% of future deforestation area does not have well defined property rights and another 8% of projected deforestation occurs in protected areas, which make these areas not eligible for REDD+ projects.

Environmental compliance	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*
Land area (ha)	128 (44)	90 (70)	74 (66)	55 (30)
Forest cover (%; 2010)[b]	87 (14)	69 (17)	44 (25)	41 (28)
Forest cleared (ha; 2008–2010)[b]	2.4 (1.8)	3.6 (4.9)	3.1 (5.7)	2.8 (5.6)
Income 2009-2010 (USD/capita)[c]	*Mean (SD); %*	*Mean (SD); %*	*Mean (SD); %*	*Mean (SD); %*
Total income	1874 (1292); 100%	2645 (5694); 100%	3439 (4813); 100%	3852 (4717); 100%
Forest income	304 (356); 16%	103 (246); 4%	130 (606); 4%	144 (609); 4%
Non-forest environ. income	48 (115); 3%	34 (65); 1%	45 (93); 1%	370 (1416); 9%
Crop income	510 (617); 27%	824 (1420); 31%	814 (1700); 24%	603 (1587); 16%
Livestock income	284 (613); 15%	920 (4687); 35%	1759 (3750); 51%	1142 (3270); 30%
Wage and business income	366 (771); 20%	385 (783); 15%	332 (949); 10%	809 (2092); 21%
Other income (e.g. aid)	362 (481); 19%	379 (632); 14%	360 (1011); 10%	784 (2581); 20%
Assets (USD/capita)	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*
Livestock herd	1294 (1790)	1991 (5113)	6370 (7953)	9352 (19720)

Source: adapted from Duchelle et al (2013)

Areas with larger forest are related with lower total income and lower cattle ranching opportunity costs. Higher value of livestock herd was related with lower forest cover. Perceived tenure security is also low in at least 3 of the 4 study sites.

Opportunity costs have some limitations to valuate natural resources and ecosystem services because the opportunity costs, in this case the forgone flow of income from cattle ranching activities, does not incorporate the forgone values of different ecosystem services like climate regulation, habitat for wildlife species or existence values. There for, this can be considered a lower bound for the valuation of ecosystem services and natural resources that come from the Amazon forest.

If we let the cattle ranching activity to be developed, one can argue that this value can be a willingness to accept from the society point of view, for accepting deforestation. The monetary value defined should then be enough to compensate the society for the forgone ecosystem values and will cover all the costs to recover the ecosystem to its initial state. May et al (2004) make an analysis of restoration costs in the Amazon forest, and show that the amount of monetary values estimated is not enough to recover ecosystem functions when using opportunity costs.

Young et al (2007) recognize some limitations for opportunity costs calculations like availability of information, in particular for land prices, diverse agriculture activities profits, and more specific data on heard population and cattle ranching sales.

Young and Bakker (2015) defined opportunity cost of land as “the value sacrificed (in monetary terms) for the abandonment of land use in agricultural activities in favor of its conservation for the maintenance of ecosystem services. That is, it is the minimum income that the rural landowner is willing to receive to conserve the remnant forest areas or to regenerate native vegetation on his property".

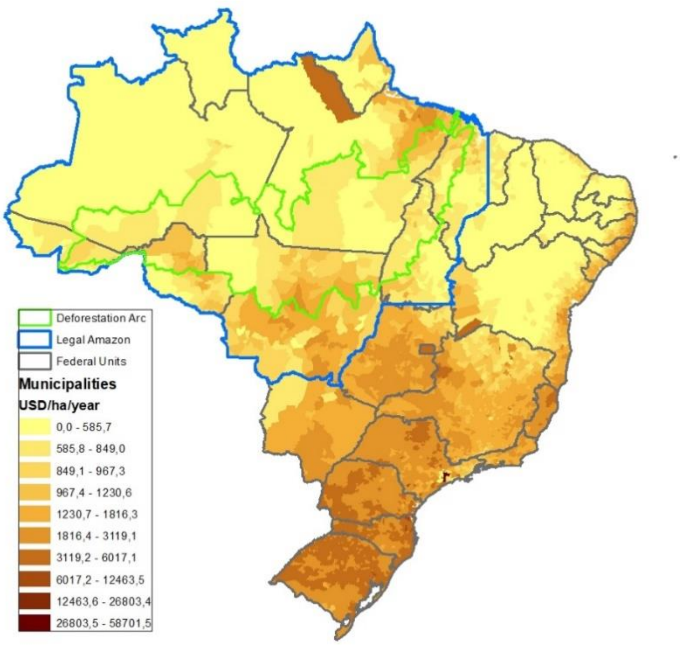
Based on this definition Young (2016) generated some estimates for Brazil by municipality. Three alternative models of the estimation of the opportunity cost of land were developed, presented as the average value (per hectare / year) of crop and livestock income sacrificed due to the option for forest conservation:

a) Estimating presumed crop, livestock and silvicultural profit as a function of IBGE data of municipal production value (Model COT - L).

b) Estimation by extrapolation of land price information, according to its use, available to a subset of municipalities (Model COT - P).

c) Estimation by econometric model of land price definition (endogenous variable) from physical and market characteristics (Model COT - E).

Authors suggested using the average value in order to distribute de error. It is worth mentioning that all three options have similar magnitudes. The price unites refer to BRL per hectare for the year 2013[10]. Oportunity cost results are presented on Map 6.

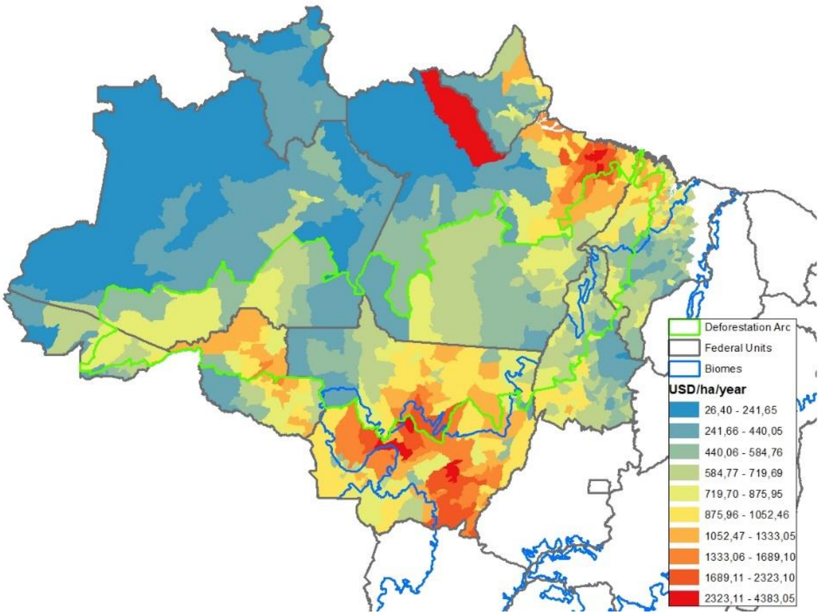


Map 6: Opportunity cost per hectare in present value for Brazil (2016 USD)

[10] We updated this information to USD for 2016. See deforestation chapter on how it was done.

Source: adapted from Young (2016)

Map 7 shows some interesting facts. First, opportunity cost is distributed not uniformly throughout Brazil, then, conservation activities show different cost-effective alternatives to achieve conservation goals. Second, depending on the scale, you can find different ways in which conservation strategies costs can be organized. Conservation costs will vary depending on the scale at which you apply different incentives PES.



Map 7: Opportunity cost per hectare, in present value, for Legal Amazon (2016 USD)

Source: adapted from Young (2016)

For Brazil median value of opportunity cost, in present value, is USD$ 1.472, 57 and municipalities below this value are located within Amazonas, Para and Northeastern states. Now if your focus is only the Amazon biome (second map), the median value is USD$ 771,41, and then interesting areas for PES establishment are located in the Amazon, Para, Tocantins and some municipalities in the northwest of Mato Grosso. Third, opportunity cost distribution, for the Legal Amazon, is clearly related areas defined by the Forest Transition Theory (settled, remote and frontier). Settled areas lie outside the deforestation arc, in the southern or Mato Grosso, northeastern Pará, and an area between Pará and Amapá. In this areas opportunity cost is higher than USD$ 1.333/ha/year. In contrast, areas that are not well connected by highways, that have not been incorporated yet to the agribusiness schemes, have a low opportunity cost, like some municipalities in Roraima, Acre, Amazonas, Pará and Tocantins. They also are related with von Thünen land rent curves: Land uses are located according to land rents. Municipalities with low opportunity costs are associated with open access forest, intermediate land rents are associated with extensive agriculture, like extensive cattle ranching, and the highest rents are associated with intensive agriculture (sugar cane, soybeans and corn). So opportunity costs can help to understand different drivers that determine land use changes and in particular, for marginal lands deforestation.

Throughout this section, we saw that agriculture and cattle ranching activities are important to identify opportunity costs, but particularly, cattle ranching emerges as a common topic in reviewed studies. Establishment of property rights is important in order to allow adequate payment of opportunity costs. Establishment of property rights can allow a wider use of REDD+ projects within de Legal Amazon.

2.4 Sustainable cattle ranching and environmental services

Seroa da Motta and Young (2012) state that while productivity has grown in Brazil, the expansion of cattle ranching continues to exert strong pressure on the agricultural frontier. Production intensification, through increasing carrying capacity per hectare, establishing silvopastoral systems (SPS) and other management landscape tools (live fences, dendroenergetic –multiple use- forests, etc.) allows to achieve productivity gains and achieve territorial planning and in properties, and are tested alternative (Nepstad et. al., 2007 and World Bank, 2010).

Silvopastoril systems (SPS)11, agroforestry systems (AFS) or agrosilvopastoral systems (ASPS) are technologies implemented at the farm to have a good land use practices. SPS are land uses that associate one or more types of shrubs/trees with grasses, legumes and herbaceous pasture (natural or planted), used for domestic animal production and production of wild animals (Murgueitio, 2004). Some of these alternatives are: cut and harvest mixed fodder banks, dispersed trees in pastures, live fences and windbreak trees, improved pastures, intense SPS with trees/shrubs in high density for grazing, reforestation of degraded areas and restoration of riparian vegetation (Murgueitio and Galindo 2008; Calle and Murgueitio 2009).

[11] In Brazil, there is an ample literature related with ASPP systems, named by Integração Lavoura Pecuaria Floresta, which are an important field of work that incorporate SPS.

ASPS are a strategy to promote sustainable production integrating and developing agricultural, livestock and forestry activities in the same area. Some ASPS activities are intercropping, in succession or rotated, and seek a synergy between agroecosystem components. It also is a system that looks for environmental suitability, recognition of human dimension, and the economic feasibility of developed activities (Balbino et al. 2011)

May (2008) recognize that in many parts of the world new opportunities are arising to add value to sustainable rural land resource management. Within these new opportunities, SPS is a new activity that is generating such value addition in rural properties.

Table 5 show that value-added activities relates with water and soil, climate change and biodiversity conservation services, as classified by May (2008). SPS activities generate this environmental services and are likely to become a Payment for Environmental Services (PES).

Table 5: Types of environmental services generated by good land use practices

Water and soil-related services	*Climate services*	*Biodiversity conservation services*
• Flow regulation; • Quality maintenance; • Aquatic habitat; • Cultural values (recreation, worship); • Control of erosion and sedimentation; • Nutrient cycling; • Reduced salinity	• Microclimate regulation • Reduced emissions from burning; • Carbon sequestration; • Maintenance of terrestrial carbon stocks	• Connectivity and scale for wildlife conservation; • Sustainable use; • Cultural values (recreation, worship, existence value)

Source: May (2008)

Schils et al (2005) recognize that ruminant livestock systems are a significant source of GHG, and most analysis center on a single gas and analyze isolated processes like animal production, manure, soil, crop and field activities (see Table 6). Single farm components can generate multiple GHG and, GHG are present in more than one farm component. Methane (CH_4) and nitrous oxide (N_2O), are present in most of livestock component. Also, soil inputs generate almost all the GHG emission in livestock systems.

Table 6: Direct emissions of methane (CH_4), nitrous oxide (NO_2), carbon dioxide (CO_2), ammonium (NH_3) and nitrate (NO_3), grouped by farm component.

Farm component		CH_4	N_2O	CO_2	NH_3	NO_3
1. *Animal*		•	•			
Input	Concentrate					
	Intake silage		•	•		
	Intake grazing					
Output	Milk					
	Meat					
	Excretion stable	•	•		•	
	Excretion pasture	•	•		•	
2. *Manure*		•	•		•	
Input	Excretion stable	•	•		•	
	Import					
	Feeding losses					
Output	Application		•	•	•	
	Export					
3. *Soil*		•	•	•		•
Input	Excretion pasture	•	•		•	
	Application		•	•	•	
	Mineral fertiliser		•	•	•	
	Harvest losses				•	
	Grazing losses				•	
	Biological fixation		•			
Output	Crop uptake					
4. *Crop*						
Input	Crop uptake					
Output	Harvest		•	•		
	Harvest losses				•	
	Grazing					
	Grazing losses				•	
5. *Feed*			•		•	
Input	Harvest		•	•		
	Import					
Output	Intake silage		•	•		
	Feeding losses					

Relevant emissions for each farm component are marked with •.

Fonte: Schils et al (2005)

Identifying the different relationships that production processes have within a livestock farm is fundamental to propose successful GHG mitigation activities. For livestock systems, and in particular for SPS it is possible to identify processes, different types of greenhouse gases emissions, and interrelation with inputs and outputs to allow to quantify and estimate the economic impacts of their implementation.

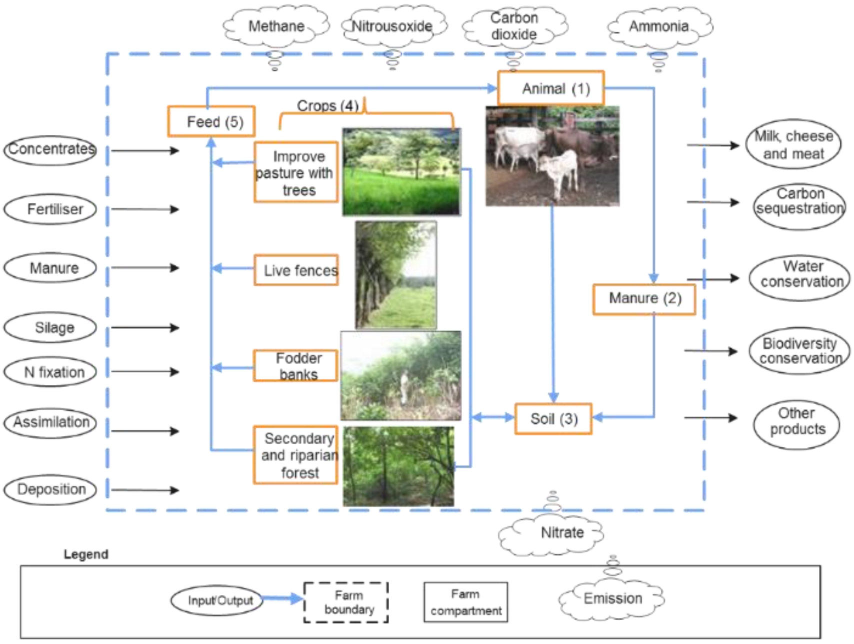


Figure 13: Greenhouse gas emissions flow diagram of a ruminant livestock system, including SPS activities.

Source: Adapted from Schils et al. (2005) and Ibrahim (2007)

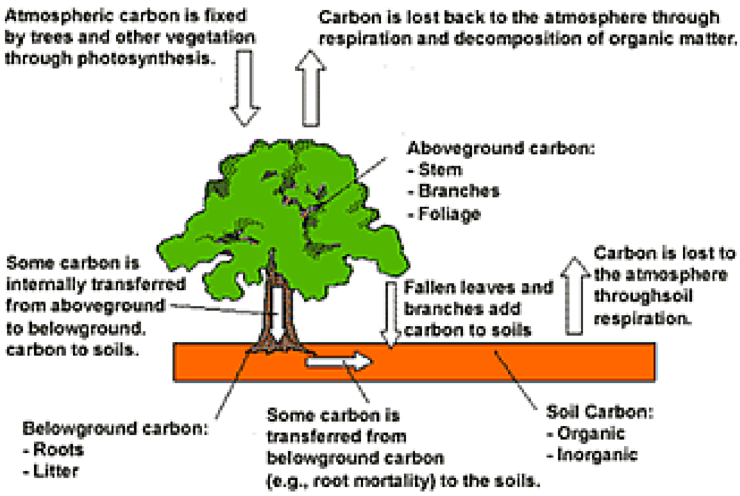
It is possible to propose a farm level framework to quantify different GHG emissions by gas type and relevant activities that can generate gas pools like animal production, crops, manure, soil and feed management. Ibrahim (2007) calculate the carbon footprint of a conventional livestock production chain based in this methodology and compare it with a SPS production. The amount of GHG emissions in SPS per unit of milk produced is half of the conventional milk production system (1,1 vs. 2,2 $KgCO_2eq$ per kg of milk corrected by % fat and %protein).

SPS are promoters of ecosystems services like carbon sequestration and deforestation reduction. Molina et al (2008) estimated that SPS (*Cynodon plectostachyus* + *Leucaena leucocephala* + *Guazuma ulmifolia*) can sequester 7,52 tC/ha, and it can capture 2,5 tC/ha/year (Colombia). Messa (2009) estimations, using IPCC methodologies, on total carbon storages for pastures with L. leucocephala presented 64,05 MgC/ha, *G. sepium* forage banks presented 67 MgC/ha and pastures with disperse trees presented MgC/ha (Venezuela). Gamma and PFPAS (2010) established that, secondary forests have 178,7 MgC/ha, enhanced pastures with trees have 107,1 MgC/ha, grass forages bank have 99,3 MgC/ha and degraded pastures 60,2 MgC/ha (Costa Rica). Naranjo et al (2012) report that degraded pastures emit 1,06 tCO_2eq/ha while enhanced pastures fix 3,3 tCO_2eq/ha, intensive SPS fix 17,0 tCO_2eq/ha and intensive SPS associated with timber species fix 34,8 tCO_2eq/ha.

Replanted areas for human use with SPS can reduce deforestation and forest degradation. CIPAV (2005) showed that one hectare planted with *Acacia melanoxylon*, *Alnus acuminata* or *Cecropia telealba* can generate 60 m^3 of timber (year 3) and up to 200 m^3 (year 7) (Colombia). Therefore, SPS have an important potential to reduce deforestation in primary and secondary forests.

Figure 14 summarizes some of the most salient carbon sequestration dynamics in SPS.

Figure 14: Carbon sequestration dynamics.



Source: USDA Forest Service (2013).

SPS and AFS help to increase aboveground biomass, as well as belowground biomass. In addition, this system has the ability to increase soil organic and inorganic carbon.

For nitrogen fixation ecosystem service, Naranjo et al. (2012) found that SPS and SPS associated with timber species don't generate emissions of NO_2 related with synthetic nitrogen fertilizers (enhanced pastures generate 876,9 $kgCO_2eq/ha/year$). For methane emissions, Naranjo et al (2012) report reductions of 30% of CH_4/kg of consumed Dry Matter emissions in Australia in SPS with *Leucaena Leucocephala* , and 38% reduction of $CH_4/animal/year$ emissions in intensive SPS in Mexico. Shibata & Terada (2010) identify that some technologies for mitigation of CH_4 emissions are: increase fattening productivity, improve grazing management, improve quality of pastures and introduction of management intensive grazing. Demarchi et al (2006) report, for Sao Paulo state (Brazil), that mean annual emissions are 52 kg CH_4/animal/year. If enhancement of nutritional handling and reduction of slaughter age are applied in beef cattle (from 4,5 years to 2 years), then it can reduce 10% methane emissions.

Calub (2003) shows that SPS and AFS are more diversified production systems and generate important social and economic impacts. Then, they reduce dependence on off-farm inputs, like animal feed and fertilizers. It also reduces family dependence on off-farm food resources and increase family nutrition diversification, achieving food security.

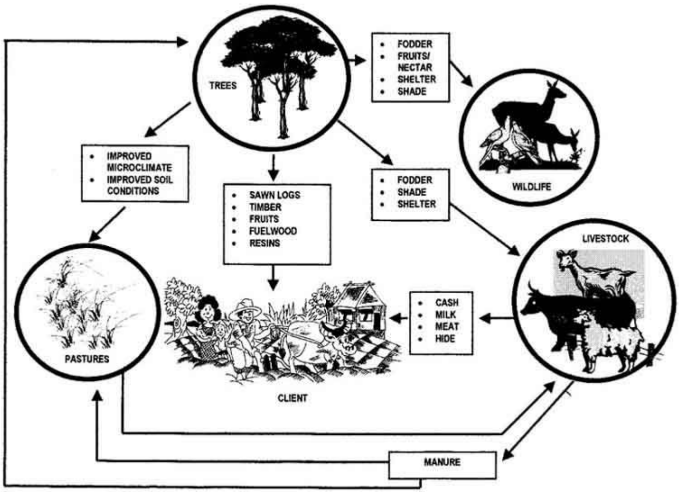


Figure 15: Benefits generated by silvopastoral system

Source: Calub (2003)

Agriculture products have price cycles that negatively affect family net income. This holds true in particular for monoculture systems. Some of the opportunity cost studies showed how agriculture producers rely in one or two products. When market prices are at peaks, family income is secure, but in months presenting low prices, family income present substantial reductions. In diversified agriculture and cattle ranching systems like SPS, AFS or ASPS, agricultural household income is equally diversified, reducing the volatility of expected income.

Some other ecosystem services related with SPS are: increase water quality in watersheds when promoting riparian forests (Chará, Pedraza & Giraldo 2008), scattered trees in pastures registered the highest number of birds even when comparison is made with secondary forests and fruit trees (Fajardo et al. 2008)

3. METHODOLOGY

3.1 General framework for deforestation, reforestation and methane emissions

Methodological steps to evaluate selected ecosystem services in cattle ranching follow Keeler et al. (2012), modifications by Raynaud et al. (2016) and Truecost (2015). Figure 16 show these steps.

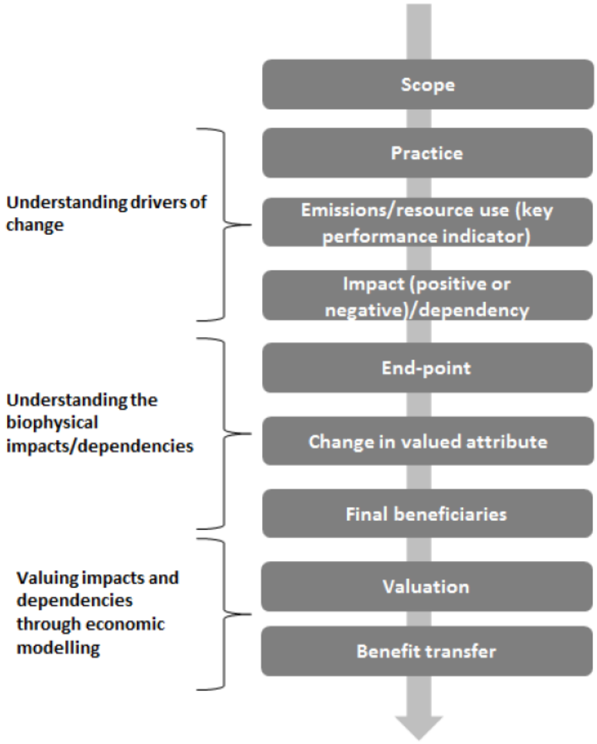


Figure 16: Framework for ecosystem services analysis.

Source: Adapted from Raynaud et al (2016) and Truecost (2015)

Below is an explanation of the methodological steps.

1. Understanding drivers of change:

The first activity defines scope and type of practices for analysis. ES analysis will cover cattle ranching in the Brazilian Legal Amazon, at the first production chain link. That is to say, beef producers at farm level and an analysis of different sustainable cattle ranching practices, in particular sustainable cattle ranching and the ES they provide.

Subsequently, we identify different key indicators, to measure the relationship between anthropic systems, agricultural and food production systems and ecosystems and biodiversity. These indicators allow evaluating dependence and impact that different drivers[12] of change have on the ecological system. Dependencies arise when agriculture and food production sectors use elements from natural capital or are essential in their production (FAO 2015, Natural Capital Coalition 2015). Likewise, impacts on natural capital can be positive or negative to the extent that agricultural activities increase or reduce their stock, consumption or restoration.

We must take information for these indicators estimations from a literature review and secondary information, or from characterization studies carried out previously in the study area.

2. Understanding biophysical impacts / dependencies:

Identification of end-points corresponds to populations that receive the identified impacts / dependencies. They are mainly cattle ranchers, but they can also be groups of society (i.e.: water users downstream, global community). For dependence analysis, source of decisions that generate changes in cattle ranching production may come from farm activities itself and from multiple external agents (i.e.: environmental or agricultural legislation).

Change in biophysical variables show how the selected indicators vary in relation to identified drivers, allowing to identify impacts through valued attributes. For cattle ranching, we analyze how indicators vary with different local conditions (at municipal level), and by the implementation of sustainable cattle ranching. We compare these practices with a business as usual situation: extensive cattle ranching practices. Then, we contrast these indicators with secondary information on existing biophysical models. Finally, we identify end-point beneficiaries / recipients of these impacts and dependencies.

3. Assessing impacts and dependencies through economic models

The evaluation group must make a trans-disciplinary work to link biological and economic indicators, identifying how physical attributes relate to bio-economic models. This generates a consistent assessment.

This is a necessary step, since process of economic valuation information consists in turning biophysical changes into monetary terms, so that changes in valued attributes become costs and

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[12] Drivers are "any natural or man-induced situation that directly or indirectly generates a change in the ecosystem" (FAO 2016)

benefits for specific beneficiaries, based on the use of valuation coefficients (Raynaud 2016). The result is then a monetary value of the contributions/damages that are generated towards ecosystems and society, and to and from agricultural and food production systems.

3.1 Dependence of cattle ranching growth on deforestation: induced innovation

Several authors have identified the relationship between cattle productivity and expansion of agricultural land, and as a consequence, a relationship with deforestation. Martha Jr, Alves and Contini (2012), Reis (2016) and Vieira Filho (2016)[13] decomposed cattle ranching productivity, based on an identity developed by Hayami and Ruttan in 1985. According Thirtle (1985), Hayami and Rutan's basic model of induce innovation in agriculture is based on the proposition that "technology can be so developed as to facilitate the substitution of relatively abundant (hence cheap) factors for relatively scarce (hence expensive) factors in the economy". This theory was developed using the following identity:

Equation 12: Hayami and Ruttan identity of induce innovation in agriculture

$$\frac{Q}{L} \equiv \left(\frac{Q}{A}\right)\left(\frac{A}{L}\right)$$

Where:

Q = output

A = land and

L = labor

Thirtle (1985) showed that output per hectare (Q/A) will increase as a result of a biological/technical change that happens when "introduction of fertilizer-responsive high-yielding crop varieties facilitates the substitution of fertilizer for land, in response to the decline in the price of fertilizer relative to land rent". In a similar way, mechanical/technical change will raise land/labor ratio (A/L), and is a result from improvements in machinery and equipment allowing labor substitution for machinery, in response to the falling price of machinery relative to labor (Thirtle 1985). As a consequence, biological/technical change is key to "green

[13] Martha Jr, Alves and Contini (2012) and Reis (2016) are focused on number of cattle heads, while Vieira Filho (2016) is centered on the evolution of cattle production in terms of weight of carcasses.

revolution", as it is a largely land saving strategy, whereas, mechanical/technical change is labor saving.

Reis (2016) made an application of the induced innovation equation to cattle ranching activities in Brazil. Their proposal for cattle ranching is as follows:

Equation 13: Cattle ranching induced innovation equation

$$C = \frac{C}{P} * \frac{P}{F} * F$$

Where C is cattle herd size, P is pasture area and F is farm area. Therefore, cattle herd size growth can be decomposed in the following components:

Equation 14: Cattle herd growth

$$gc = gcp + gpf + gf$$

Cattle herd growth (gc) is additively decomposed in: stocking ratio or number of heads per hectare of pasture (gcp) growth, as a measure of pastures' productivity increase; growth of pastures share in farm area, as a measure of specialization in cattle ranching activities; and farm area (gf) growth is an indicator of global agricultural activities growth.

Reis (2016) suggested inclusion of overall agricultural areas, including pastures, crop, fallow areas, agriculture and planted forests, to make deforestation part of the analysis. Since, in the Brazilian Amazon, agricultural areas' growth is almost identical to deforestation, this specification will allow including deforestation into cattle ranching productivity analysis. The proposed equation, following this modification, is:

Equation 15: cattle ranching induced innovation equation, including overall agricultural area

$$C = \frac{C}{P} * \frac{P}{A} * \frac{A}{F} * F$$

Where A is overall agricultural land.

3.2 Deforestation methodologies:

This chapter develops a deforestation projection model for the Brazilian Legal Amazon, based on two scenarios: Business as Usual (BAU), which assumes that there is a weak public policy for deforestation control; the other, assumes that there are some policy efforts to control deforestation, in particular on main deforestation drivers like cattle ranching, illegal logging and agricultural activity. We assume this scenario to be a sustainable ecosystem management (SEM). We estimate municipal yearly deforestation rates for the Legal Amazon biomes, and also, its spatial distribution. We follow Bovarnick and Alpizar (2010), because they clearly state costs and benefits for each scenario of ecosystem management, and allow connecting scenarios results with policy recommendations. In addition, improvements (degradation) in ecosystem services can be understand in terms of economic benefits (loses) for different ES users, so it is possible to identify the effect of different incentives (positive or negative) on the net economic benefits and on the ES provision in the short and long run. For a more complete analysis on this methodology see Annex 5.

3.2.1 Business as usual scenario (BAU)

Forest Reference Emissions Level is a term used under the United Nations Framework Convention on Climate Change (UNFCCC). This reference level defines a baseline that allows evaluating each country's performance implementing activities like: National Appropriate Mitigation Actions (NAMAs), Policy approaches and positive incentives, use of markets and promotion of cost-effective mitigation actions[14]. These actions allow to:

(a) Reduce emissions from deforestation

(b) Reduce emissions from forest degradation

(c) Conservation of forest carbon stocks

(d) Sustainable management of forests

(e) Enhancement of forest carbon stocks

So, comparing actual trends with historical or projected deforestation and emissions trends, it is possible to identify "actual effects of policies and measures to reduce emissions from deforestation and forest degradation in developing countries and the role of conservation, sustainable forest management and enhancement of forest carbon stocks (REDD+)" (MMA, 2016).

[14] See United Nations Framework Convention on Climate Change, Decision 1/CP 16, document established in Cancun 2010, during the 16th Conference of the Parties.

The Brazilian Government issued in 2014 a policy document with the methodology to define the forest reference emissions level, that is the base for a possible payment for Reduced Emissions from Deforestation and forest Degradation (REDD) policy (MMA, 2014).

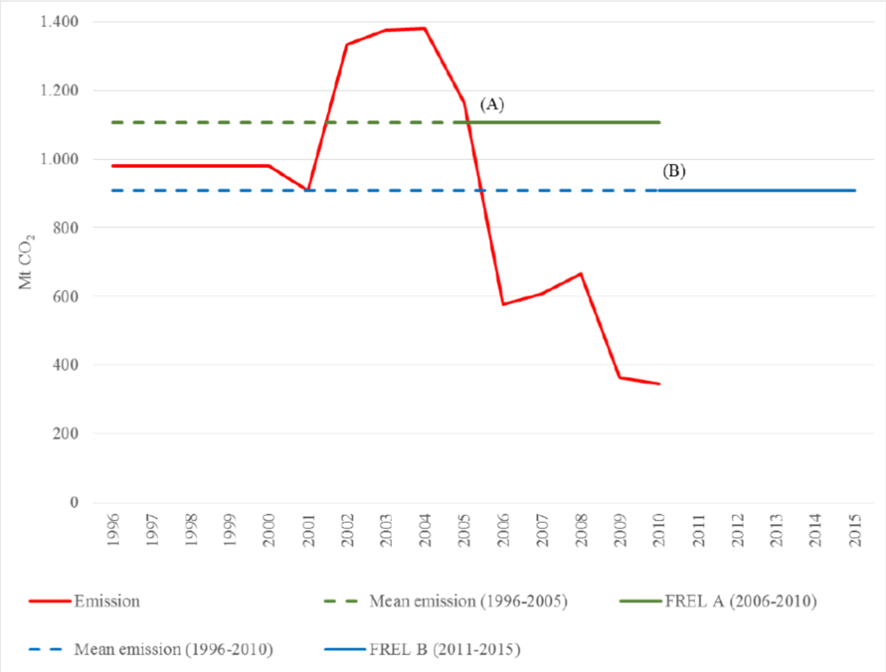


Figure 17: Pictorial representation of Brazil's FREL

Source: adapted from MMA and MCTI (2014).

(A) refers to the mean annual CO_2 emissions from the period 1996 to 2005; (B) refers to the mean annual CO_2 emissions from the period 1996 to 2010.

3.2.2 SISGEMA

It was necessary to build two hypothetical scenarios, to calculate total emissions that would be avoided by forest conservation: (i) a business as usual (BAU) scenario, revealing deforestation trend, in the absence of a PES; (ii) a desirable scenario, estimating the trajectory of deforestation rates in a context marked by the presence of a PES (SEM scenario).

Literature presents different methods for different biomes' deforestation projection and for Brazil (Cunha et al. 2015, Lima 2014, WWF 2014, Yanai et al. 2012, FAS 2013). In this subsection, we opted for a model obtained by the inverse of the exponential function, whose projections pointed to an asymptotic reduction of deforestation rates over 2016-2030. We choose this model because it is compatibile with the forest transition theory (see figure 18).

According to the FTT, countries go through different stages, based on the amount of deforestation according to their development stage, the amount of forests available (forest remnants), and their ability to control deforestation. Different texts locate Brazil in step 2, where there is high deforestation and high forests remnants. According to the latest available data, the Brazilian government has generated a very significant deforestation reduction in Legal Amazon up to 2013, showing that it is changing from phase 2 to phase 3 of the FTT, where forest mosaics and low deforestation are happening. This seems to capture what happens with different Brazilian biomes at different stages. For example, Mata Atlântica biome presents very low rates of deforestation and low remains, and can be classified at the beginning of phase 4.

According to these considerations, deforestation projections needed to show this biome's deforestation decline. We tested different models using historical deforestation series, to generate a very simple deforestation projection: linear model, quadratic model, exponential. Inverse exponential function showed the best results, using only the historical deforestation information.

Accordingly, we designed SISGEMA model. This model projects future deforestation by extrapolating forest remnants' trend lines, for each Brazilian municipality. The format of this trend line is described by the inverse of an exponential function, parameterized for each municipality. Equation 6, show this result.

Equation 16: SISGEMA projection function

$$D_{ijt} = \left(D_{jt0} * e^{-g_j t}\right) * MP_{it-6}$$

Here, D_{ijt} is deforestation area for municipality *i*, in biome *j*, in period *t*; D_{jt0} is the area of deforestation in biome *j* in the initial period of the analysis (*t0*) and g_j is the rate of deforestation in biome *j*. MP_{it-6} is the average participation of municipality *i*, in biome *j* deforestation within the 6 years prior to the initial projection period. Thus, recent deforestation history in each biome is considered for remnants projection per municipality.

Because of this functional form, projections point to an asymptotic reduction in deforestation rates over 2016-2030, which is compatible with the forest transition theory (Figure 18). Annex 6, shows deforestation equations calculated for each biome.

One characteristic of exponential function growth rate, is that it is directly proportional to the value of the function in a specific time. In our case, deforestation growth rate will depend on the current values of the rate, and the rate will depend on values of remaining forests. This feature is also compatible with the FTT, because low remnants are associated with low deforestation rates, and therefore deforestation will have a downward trend to zero, until the end of phase 3 (see graph 18). This justifies the selection of an exponential model of decay. We did not model forest recovery, which corresponds to phase 4.

3.2.3 Dinamica EGO

Dinamica Ego uses an economic and environmental model for deforestation expansion, as proposed by Soares-Filho, Cerqueira and Pennachi (2002) and Soares-Filho et al. (2006). To perform it, we use spatial and environmental modeling software called Dinamica EGO. Dinamica EGO is an explicit spatial simulation platform for landscape dynamics. This software uses a cellular automata[15] model, to work at different scales and generate rules of change according to neighboring cells' characteristics. It also incorporates spatial feedback along with a multi-step simulations program to calculate transition probabilities over time (Soares-Filho, Cerqueira and Pennachi 2002).

According to Mas et al. (2014), different models of land use change and cover, follow in general three steps: a) calibration, b) simulation, 3) evaluation. Figure 18 identifies different stages in the modeling processes of land use and land cover changes.

[15] A cellular automata is a discrete model that consists of a network of cells that can take different values according to some defined rules. For example, a cell cataloged as a forest would change to a non-forest value in the case of a change in land use, according to a given pattern.

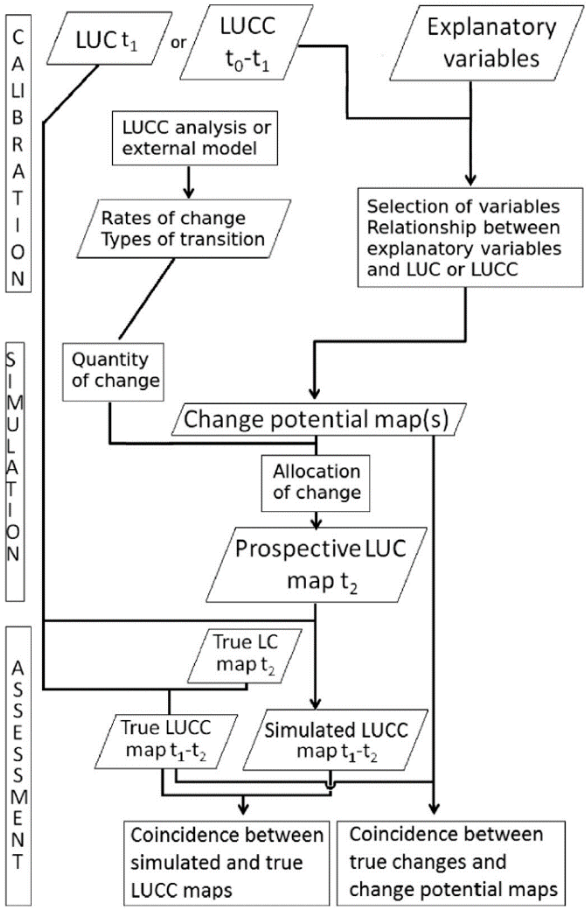


Figure 18: Flowchart of the general procedure used in LUCC modeling

Source: Mas et al. (2014).

Note: The rectangle shape indicates a process, the parallelogram inputs to and outputs from a process.

The first step is to identify variables that influence land use and land use change. After a literature review, a land change model can be developed to identify most relevant variables, related different theories on deforestation determinants. For Soares-Filho et al. (2009), the process of land use change simulation can be summarized in 10 (ten) steps, as shown in Figure 19.

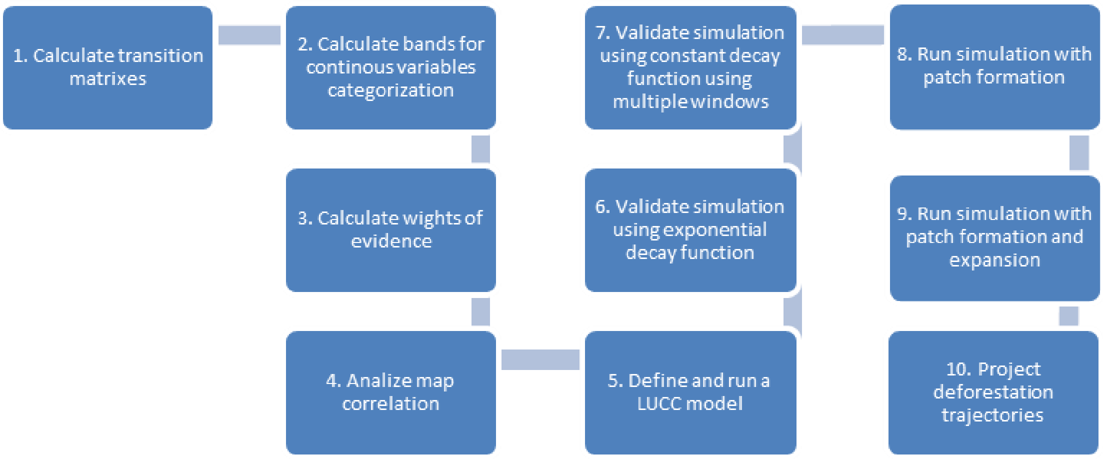


Figure 19: Ten steps for Land Use and Cover Change simulation model

Source: adapted from Soares Filho et al. (2009)

The process begins with land use and land cover map identification for an initial period (t_0) and for a later period (t_1). By comparing these maps, it is possible to identify how much land use has varied in the chosen landscape over a period of time. These variations, arranged in a matrix form (transition matrix), serve as a basis for future projections. Alternatively, another way of calculating the transition matrix is to use the coefficients of an econometric regression containing the set of explanatory variables and to determine the rates of change between types of land uses in a landscape over time.

Mas et al. (2014) identify, in the calibration phase, variables that will be included in weights of evidence analysis. First, they perform a variables correlation analysis, to exclude those with high correlation. Second, they calculate how much each variable contributes to change land use probability (weight of evidence). Examples of variables calculated with this methodology are: distance to roads, distance to rivers, distance to cities or populated centers, altitude, slope, among others. These weights are adjusted for each variable by a given range of values, and are then analyzed together to generate a probability map. The probability map indicates areas where future deforestation most likely will occur.

Knowing distribution on deforestation probability in the study area, one can start the simulation stage (Mas et al., 2014). At this stage, chosen physical and socioeconomic variables for the same area, are used, first generating a deforestation map for period t_0 and projecting deforestation dynamics up to period t_1. Then, validation is carried out, identifying similarity between simulated t_1 map and observed t_1 to quantify accuracy (evaluation phase, according to Mas et al., 2014).

Dinamica EGO software employs simulated and observed mapping similarity analysis on different windows or groups of pixels. Thus, "if the same number of change cells is found inside the window, the adjustment will have value of 1, regardless of their locations" (Soares-Filho et al., 2009). For our case, it was done increasing groups of pixels, which represents an analysis in a smaller resolution window - the size of the window should be selected using a constant decay function.

Similarity analysis was carried out, running again the model, including expansion of deforestation areas on the map (using the so called expander functor[16]) or the formation of new deforestation areas (using the patcher functor). Finally, it was possible to generate a deforestation projection for the desired year. Described analysis made use years 2002 and 2008 information, for periods t_0 and t_1.

We identified different variables related to deforestation rates, and the methodology used to carry out these analyzes, after reviewing secondary information on determinants of deforestation in the Brazilian biomes.

Table 7 shows spatial and socioeconomic data by municipality that were identified as relevant, as well as their sources.

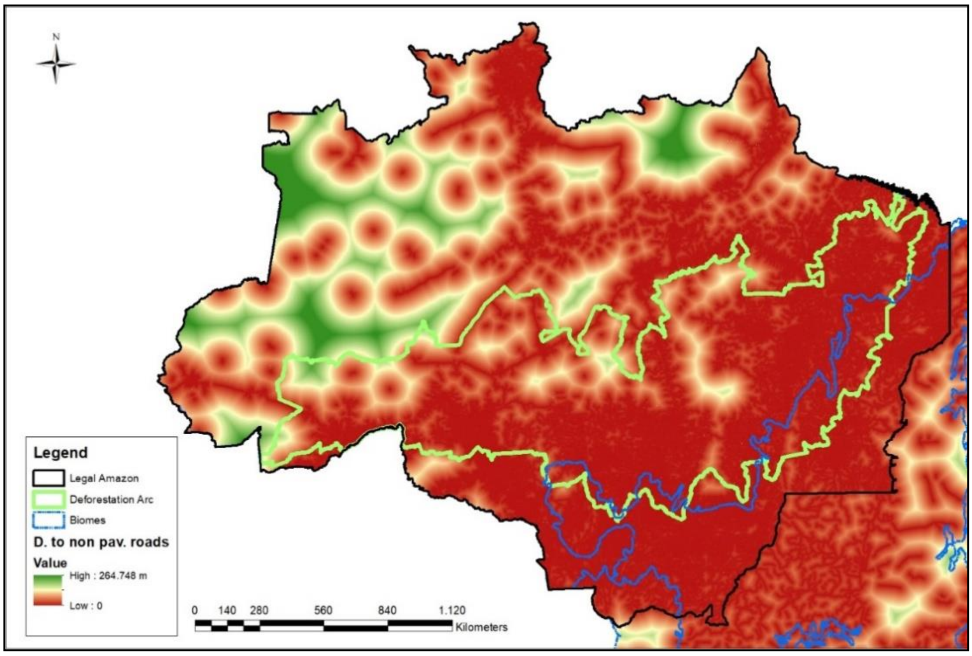
Table 7: Spatial relevant data used to model deforestation in Amazon and Cerrado biomes.

Variables	Source
Roads (Paved and Unpaved)	LAPIG/DNIT, CSR
Historical Deforestation	INPE, PMDBBS, etc
Waterway	DNIT
Altimetry	UFGM
Declivity	GEMA based on UFMG
Types of soil	EMBRAPASOLOS
Types of Vegetation	RADAM/IBGE, MMA
Population nuclei	IBGE
Protected and indigenous areas	IBGE 250 thousand base, ICMBio
Water deficit	LAPIG

[16] Functors are pre-stablished routines that generate specific tasks.

Source: own elaboration

Selected variables are consistent with theoretical deforestation determinants: forest areas near to roads, waterways, populated areas, tend to be deforested first. With this information we generate a "distance to" map, using Dinamica EGO "functor". The following maps are two examples of using the "distance to" functor.

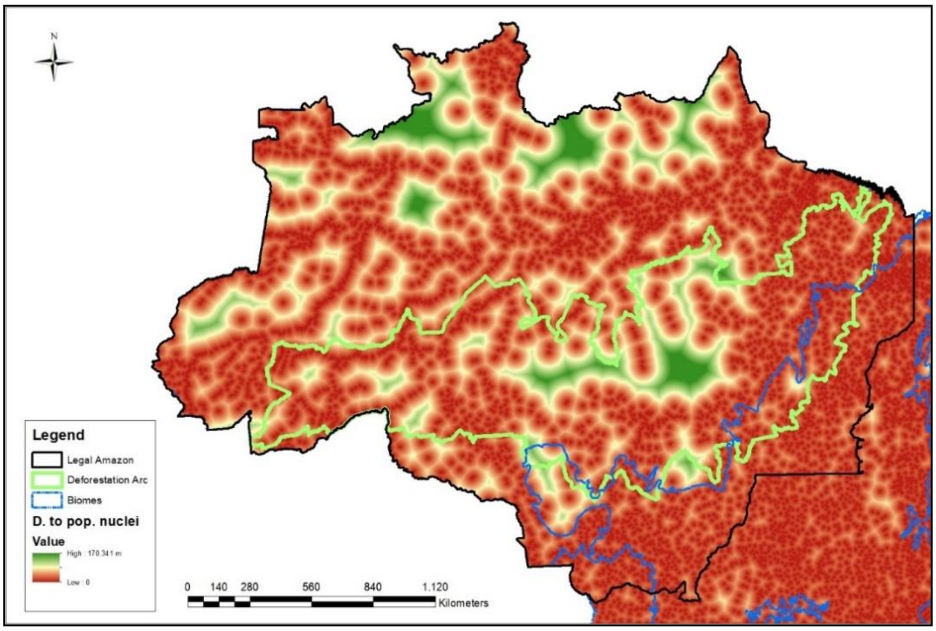


Map 8: Distance to non-paved roads.

Source: own elaboration using IBGE information and Dinamica EGO.

Distance to non-paved roads, in

Map 8 is a key driver to understand deforestation. As was seen on deforestation drivers, roads expansion has been identified as an increasing deforestation factor. Roads, paved and non-paved, allow forest users to take advantage of most valuable forest, starting a process of degradation. Later, other forest with lowest values are used, for other activities like building or in the worst case scenario for burning, in order to incorporate in the new agricultural soils some "natural fertilizers" from the slash-and-burning process. Therefore, some of the areas that are initially deforested are those that are closer to paved and non-paved roads.



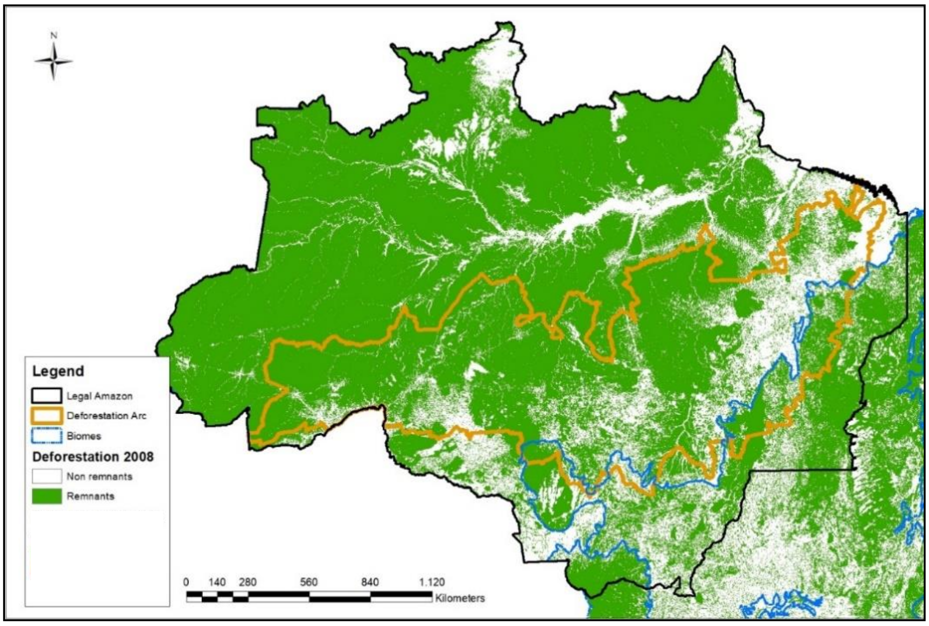
Map 9: Distance to population nuclei different from large cities.

Source: own elaboration using IBGE information and Dinamica EGO.

Map 9 shows a similar situation as the one described for roads. Forest areas closer to populated areas are more likely to be deforested. Then, red color shows higher pressure to forests and green color show lower pressure because forests are located further form human settlements. **Map 9** also illustrates one important characteristic of the forest transition theory: if a forest area is closer to some population nuclei, it has a higher deforestation probability. Forests closer to populated areas, have lower transportation costs, and present higher net returns in comparison with forests that are further away from populated areas. In addition, increasing population, in an agricultural frontier, increases the demand for certain basic consumption products, like agricultural products, so, there is an incentive to change forest land to agriculture or livestock uses.

Finally, there is also a land speculation motivation. Land speculators promote land use changes (deforestation) near forested areas, because this lands have low productivity (in terms of agriculture or cattle ranching production), but it is enough to sustain initial settlers, until they make land "improvement" buy cutting trees and establishing initial agricultural activities. So, distance to population areas is key in transforming forest land to agricultural land process. This map can help in identifying if there is a relationship between observed deforestation and distance to populated areas.

Spatial information was transformed into raster format (image) with a 250 meters per pixel resolution. Therefore, each pixel has an area of 62.500 m^2, or 6,25 hectares. To carry out model calibration, data from the Brazilian Biomass Monitoring Program (PMDBBS) was used for 2002 and 2008. These information corresponds to maps t_0 and t_1. Map 10 shows data on remnants and, anthropic or deforested areas in 2008 for Brazil's Legal Amazon.



Map 10: Forest remnants 2008.

Source: own elaboration based on PMDBBS.

Comparison of different maps from a multi-temporal point of view allows identifying the transition from one period to another period. In other words, forest and non-forest comparisons allow to identify the amount of deforestation that is occurring between two periods. Later, location is adjusted by calculating the probability of occurrence of deforestation in a specific area, creating a probability map, form the analysis of different layers like the ones presented in

Map 8 and **Map 9**. With these forest "clearing" areas, it is possible to determine a business as usual scenario, which shows the most likely behavior.

3.2.4 Quantifying avoided deforestation:

Once in possession of spatial deforestation projections, it is possible to estimate how much it would be possible to reduce deforested area as a function of a forest conservation PES.

Deforestation reduction potential depends on the value per hectare paid by a PES. This value was arbitrarily set at the median opportunity cost of land. Thus, the question that will be answered is: given the deforestation projections, which would be deforested area reduction by paying for environmental services on a determined amount of money? This amount can be calculated, for example, from the median or mean observed values[17].

Finally, it was possible to estimate the carbon emission that would be avoided due to the implementation of a PES for forest conservation and avoided deforestation. The total value of the benefit, measured in terms of tons of carbon, was obtained according to equation 7, as follows:

Equation 17: Avoided carbon emissions estimation for deforestation reduction

$$E = D * A$$

Where:

E = Reduction of carbon emitted by forest conservation (in tons of carbon);
D = Aboveground carbon density (tons of carbon / hectare) (MCT, 2010);
A = Reduction of deforested area given the establishment of a PES (in hectares);

The aboveground carbon density was obtained from the study of the Science, Applications and Space Technologies Foundation - FUNCATE (MCT, 2010). Avoided deforestation potential is calculated per biome, in tons of carbon.

3.3 Reforestation

For areas where there is no longer a trend of deforestation due to scarcity of forest remnants, the estimated cost of implementing PES should take into account opportunity cost of land and recovering costs of native vegetation in areas already deforested. This section develops a model for estimating forest recovery costs for the national territory, but we center our analysis on Legal Amazon biomes.

A bibliographical survey was carried out on the costs related to the enclosure of the land, without sowing trees, and recovery with diverse forest species. The methodological steps were as follows:

[17] Later we will see that for the whole country, the median value for the opportunity cost was BRL$ 402.57 / ha / year, in current reais for 2013 (approximately USD$ 143, for the year 2016).

A) Revision of secondary information and technical studies per biome to identify quantities per hectare or per seedling for fencing and reforestation activities.

B) Definition of a structure of basic quantities per hectare or per seedling differentiated for each of the Brazilian biomes, for fencing and reforestation.

C) Identification of databases (state or municipal) with prices of inputs used in the structure of basic quantities.

D) Creation of a database on fencing and reforestation costs, per hectare per municipality.

E) Generation of a query worksheet that allows variation of some prices and quantities, to generate different scenarios.

With this information, it was possible to establish the following equation for fencing costs of areas under forest recovery

Equation 18: Fencing costs

$$CC_k = \left[\left(\sum_{i=1}^{n} PI_{ij} * QI_i \right) + PM_j * QM \right] * QCm$$

Where:

• CCk is the cost of fencing in county k per hectare in recovery

• PIij is the state price of input i in state j

• IQ are the quantities of the inputs used in the enclosure, per linear kilometer

• PMj is the price of labor in state j

• QM is the amount of manpower employed for the enclosure per linear kilometer

• QCm is a factor that shows the amount of linear kilometers of about to be used per hectare of recoverable area

The reforestation costs are presented in the following equation:

Equation 19: Reforestation costs

$$CRk = CL + CE + CM_2 + CM_3$$

Where:

• CL is land-cleaning costs

• EC are establishing seedlings costs

• CM_2 is maintenance cost in year 2

• CM_3 is maintenance cost in year 3.

Previous equation can be rearranged according to the quantities and prices used in each phase as follows:

Equation 20: Reforestation costs, based on input costs

$$CR_k = (QIL_{ib}*PI_{ij} + QML_b*PM_j) + (QIE_{ib}* PI_j * QA_b + QME_b\ PM_j *QA_b) + (QI_{im2b}\ PI_{ij}\ QA_b + QM_{m2b}\ PMj*QA_b) + (QM_{m3b}\ PMj*QA_b)$$

Where:

• CR_k are the recovery costs per hectare in the municipality k

• QIL_{ib} is the amount of input i to be used per hectare for biome b during cleaning of the area to be recovered

• PI_{ij} is the price of input i in state j

• QML_b is the amount of manpower per hectare for biome b, in the cleaning of the area to be recovered

• QIE_{ib} is the amount of input i per seedling, for biome b, to be used during the establishment

• QA_b is the number of seedlings per hectare for biome b

• QME_b is the amount of labor per seedling for biome b, for the establishment.

• PM_j is the price of labor in state j

• QI_{im2b} is the amount of input i per seedling, in the second year's maintenance, for biome b.

• QM_{m2b} is the amount of labor per seedling, in the second year's maintenance, for biome b

• QM_{m3b} is the amount of labor per seedling, in the third year’s maintenance, for biome b

Two additional costs were incorporated into the spreadsheet for both fencing costs and reforestation costs. First, inputs' transportation costs to the workplace was calculated as a percentage of input costs and was added to total costs (the reference value is 15%). Second, a project management cost was added to the previous total costs, which already include transport costs (the reference value of this cost is 10%).

Review of secondary information and technical studies identified eleven studies to determine most frequently used inputs for recovery and reforestation of native vegetation, and the quantities of these inputs per hectare. Information was mainly collected on agricultural labor, fertilizers, agrochemicals and seedlings (see Annex 7)Annex 7: Sources for fencing and reforestation costs.. In addition to the information on the most used inputs for the recovery of native vegetation and the quantities of these inputs per hectare, we consulted twelve studies on the forest species that are recommended for recovery in the different Brazilian biomes. Current prices were identified for agricultural inputs, such as fertilizers, herbicides, insecticides, pesticides and seedlings (see Annex 7).

Seedling prices registered important variations depending on information source and some sources had both the wholesale and retail prices.

It was possible to build recovery cost matrices by biome, state and municipality, according to the best available data, after unitary prices and quantities (per hectare) were collected. Due to the absence of municipal information, input prices were consolidated at the state level, while costs were generated at the municipal level, taking into account other variables.

Land slope was considered within the structure of environmental recovery costs. According to Depra et al. (2009) declivity is a key factor because the amount of seedlings to be used in areas that previously had herbaceous vegetation is proportional to slope. Accepting this proposal, an estimate of high density (slope greater than 25%) and low (slope less than 25%) was made for different Legal Amazon biomes.

Table 8 shows that seedling densities per hectare can range from 1.300 to 1.600 at low density, and from 2.200 to 2.500 at high density. For the Legal Amazon biomes, this range goes from 1.334 to 2.500 seedlings per hectare. Analyzes were done using seedling density for mean slope of each Legal Amazon municipality and for the whole country. This is a necessary approximation for the national scale of the proposed exercise, and in particular, for each biome;

for smaller areas, adjustments must be made to planting densities according to needs and characteristics of area intended to be reforested.

Table 8: Number of seedlings per hectare for different types of slope, by biomes, for Legal Amazon.

System	Biome		
	Amazon	Pampa, Mata Atlântica	Pantanal, Caatinga, Cerrado
Low density (slope <25%)	1.406	1.666	1.334
High density (slope > 25%)	2.500.	2.500	2.224

Source: elaboration based on Depra et al. (2009).

3.4 CO_2 emissions reduction: opportunity costs and environmental supply curves.

Avoided deforestation areas can also be interpreted from the equivalent price of an equivalent carbon dioxide ton (tCO_2eq), based on the opportunity costs. This value was compared with forest carbon density per hectare values. Calculations of the equivalent price per ton of carbon (P tCO_2eq) for avoided deforestation projections were done using part of the methodology proposed by Börner et. al (2010), as follows:

1. We defined a time frame, from 2016 to 2030, for a total of 15 years. In this period, owners would generate equal net profits in each of the 15 years, therefore, they should be compensated by their annual opportunity cost in net present value.

2. To calculate the net present value, the annual opportunity cost was taken as the fixed value, assuming that it does not change during the fifteen years, and corresponds to producer's annual income. Source of opportunity costs data was Young (2016). These amounts were brought to net present value (NPV) using a discount rate of 6% annual effective rate.

3. After calculating opportunity cost per hectare, average carbon density per hectare per municipality was calculated, based on data from FUNCATE (Dos Santos, 2010). Then carbon density was divided by opportunity cost per hectare in NPV.

4. Average carbon density per hectare was multiplied by the factor 44/12 to convert into equivalent carbon dioxide (CO_2eq) tons per hectare.

5. Thus, it was possible to obtain an estimate in reais per ton of carbon equivalent ($R / tCO_2eq), of the price per ton of carbon.

6. Later, this value was adjusted using GDP implicit deflator, up to 2016, and the value adjusted to US dollars, using 2016 exchange rate.

7. Afterwards, municipalities with the lowest price for CO_2 were ordered and compared with the amount of deforestation that was potentially avoided. Finally, these areas were accumulated to construct the abatement cost curve.

3.5 Carbon dioxide captured through reforestation

Relevant information for the calculation of carbon capture potential, consists of natural regeneration rate, defined at tC / hectare / year, associated to degraded areas recovery. Palermo (2011) presents biome level results, based on a review of available literature. The following table shows the carbon capture by reforestation in each biome.

Table 9: Carbon capture from reforestation by biomes

Biome	Regeneration rate carbon capture (tC/ha/year)
Amazon	7,23
Mata Atlântica	6,92
Cerrado	2,63
Caatinga	1,75
Pantanal	2,63
Pampas	1,5

Source: adapted from Palermo (2011)

Following the information on native forest's regeneration rate available by biome, it is possible to associate it to each municipality. We use QGIS software to cut the municipality area and associate remnant areas and estimation of environmental deficit for the fulfillment of New Forest Code, following Soares-Filho et. al (2014) estimates. Based on that information we can determine forest recovery carbon captured, following this equation:

Equation 21:Carbon capture from reforestation to comply with Forest Code

$$C = R * A$$

Where:

C = carbon captured by reforestation (tons)

R = Natural regeneration rate (Palermo, 2011), in tC/ha/year

A = Deficit area to comply with new Forest Code's Legal Reserve (Soares-Filho, 2014), in hectares

We don't include reforestation of Areas of Permanent Preservation (APP). "APPs include both Riparian Preservation Areas (RPAs) that protect riverside forest buffers, and Hilltop Preservation Areas (HPAs) at hilltops, high elevations, and steep slopes" (Soares-Filho et al., 2014). To define APP's reforestation needs a georeferenced database of watersheds, or catchments, is required, which is not yet available in Brazil. "Without this database, it is difficult to analyze the riparian APP areas—that, by law, must be located on the borders of reservoirs, rivers, springs, and ponds—which may result in negative conservation outcomes" (Machado and Anderson, 2016).

3.6 Methane emissions from cattle ranching

We used an adaptation of Izko and Burneo (2003) to estimate methane emissions, as shown in the following equation.

Equation 22: Methane emissions estimations

$$C_{cat} = Ei * Mi$$

Where:

C_{cat}: cattle ranching emissions (kgCH_4/year)

Ei: emission factor by type of livestock, expressed in CH_4 kilograms (kgCH_4/year)

Mi: livestock heard (number of heads)

Emission factor by type of livestock was estimated in a study by the Ministry of Science and Technology (MCT, 2010) that presents estimates for methane emission (CH_4) by cattle herd in all Brazilian Federal Units. MCT (2010) presents methane emission from both beef cattle (young, female and male) and dairy cattle (females) with annual information from 1990 to 2006. The unit of measurement presented is CH_4kg/head/year. The same emission factor from Federal

Units was assumed for their respective municipalities. Municipalities for the Legal Amazon were chosen for the analysis[18].

Calculation of the average of the historical series of emission factor (annual from 1990-2006) was used, and the same proportion of young cattle/adult cattle observed in the female cattle for dairy cattle (females) was used, as shown by Table 10.

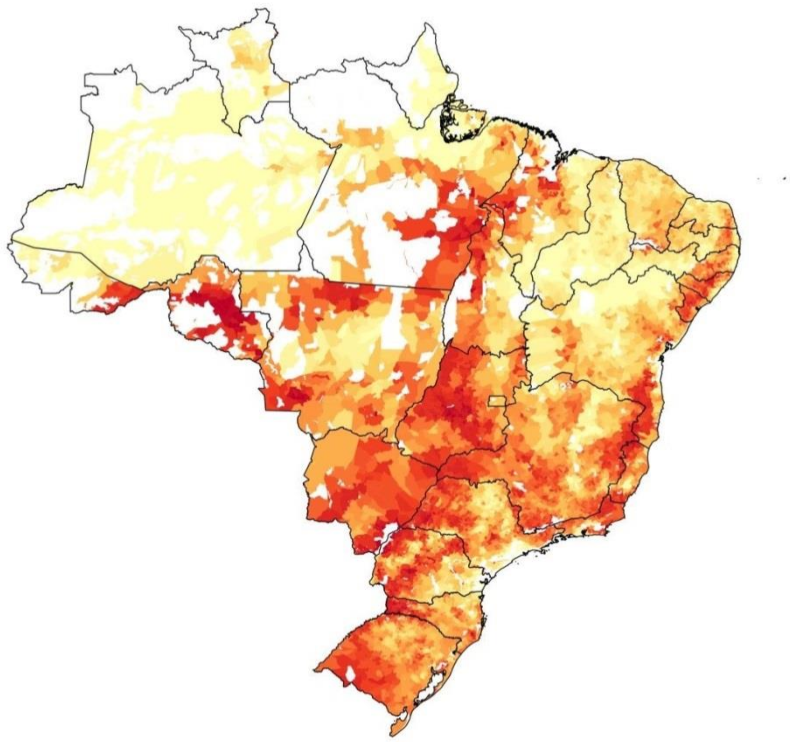
Table 10: Methane (CH_4) emissions factor for enteric fermentation by Federal Unit. CH_4 kg/head/year.

		Beef cattle				Dairy cattle		
UF	**Males**	**Calves**	**Females**	**Female**	**% of beef calves to beef females**	**Calves**	**% of beef males to beef females**	**Males**
AC	55,0	42,7	60,8	61,7	-30%	43,3	-10%	55,8
AM	55,0	42,7	60,8	61,7	-30%	43,3	-9%	55,9
AP	55,0	42,7	59,4	60,3	-28%	43,3	-7%	55,9
MA	61,0	47,3	64,3	60,1	-26%	44,3	-5%	57,0
MT	56,0	43,0	66,5	65,5	-35%	42,4	-16%	55,2
PA	55,0	42,7	58,7	59,7	-27%	43,4	-6%	55,9
RO	55,0	42,7	62,8	63,8	-32%	43,3	-12%	55,9
RR	55,0	42,7	56,8	57,8	-25%	43,4	-3%	56,0
TO	55,0	42,7	58,1	59,2	-27%	43,4	-5%	56,0

Source: extracted from MCT (2013)

[18] In some cases, it is important to map Legal Amazon (LA) values as well as the whole country values, in order to identify trends that are affecting LA observed values.

Methane emissions from enteric fermentation used cattle population estimates by the Brazilian Institute of Geography and Statistics (IBGE), from Municipal Livestock Production (PPM) survey, with annual information from 2000 to 2013. Information regarding pasture area per municipality in Brazil (LAPIG, 1996; IBGE, 2006; Soares-Filho, 2014) exist, but present problems on stocking rate per municipality, since some municipalities have a stocking rate over 100 cattle head per pasture hectare, and that is clearly an unrealistic value. This is due, probably, by the displacement of livestock and the underestimation of pasture areas. We estimate the area available for grazing, obtained by the difference between the total area of the municipality and other uses, such as conservation units and indigenous lands, for the calculation of an adjusted bovine density by municipality.



Map 11: Cattle density (number of cattle heads/ total municipal area excluding protected areas)

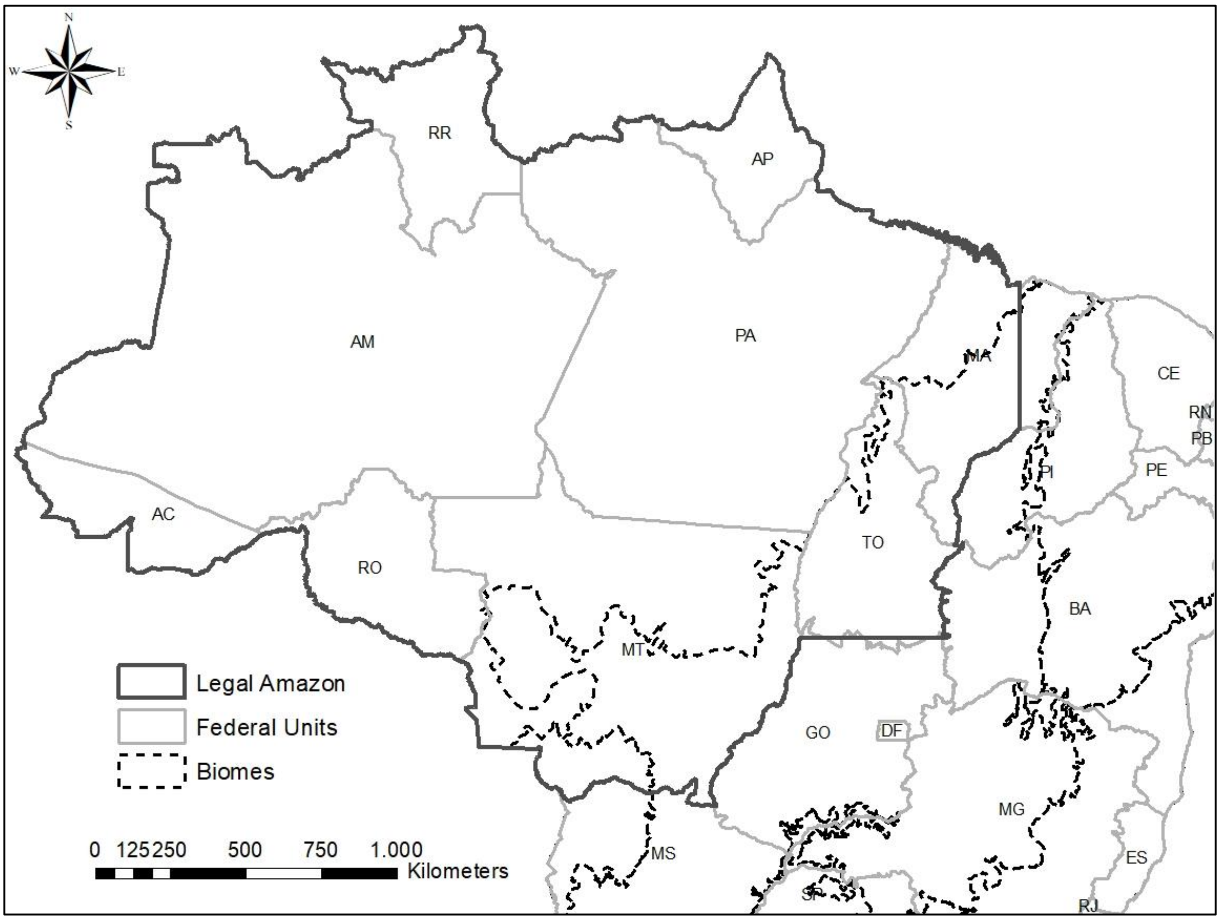
Source: elaboration based on IBGE's PPM.

Information on cattle population from the PPM is not sufficient since the information is not available by type of livestock: distribution between dairy and beef cattle, between young and adult, and between females and males. In order to estimate these differences, we used the information by type of cattle breeding and its purpose obtained by the Agricultural Census in 2005/2006 (IBGE, 2006). This information presents the percentage of each breeding, by production purpose by municipality: female, male and calves for beef cattle; female, male and calves for dairy cattle; and female, male and calves for working cattle. We assumed that the percentage of cattle by each type of livestock and purpose, described in the Municipal Livestock Research - PPM (IBGE) is constant for the entire historical series (2000-2013)

Multiplication of bovine herds by emission factor - both information by municipality, by type of livestock (calves, male and female) and by purpose (dairy, beef and work) - determines the annual methane (CH_4) municipal emissions during 2000- 2013.

3.7 Study area

The study area corresponds to the Legal Amazon. According to IPEA (2008), the Legal Amazon "is an area that corresponds to 59% of the Brazilian territory and encompasses all eight states (Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins) and part of Maranhão State (west of the meridian of 44ºW), totaling 5.0 million km²". For SUDAM (2018), Legal Amazon is a political concept, rather than a geographic one, that has been evolving since 1953, up to the new constitution in 1988. It is also a definition used for economic planning.



Map 12: Amazon biome, Legal Amazonia and Brazilian states

Source: own elaboration.

4. CATTLE RANCHING, DEFORESTATION, REFORESTATION AND CARBON DIOXIDE EMISSIONS REDUCTION

4.1 Understanding drivers of change

In previous chapters we identified some of the most salient drivers on deforestation. In these chapter we want to explore some key variables (i.e. forests remnants, cattle herd growth) dynamics in order to identify possible patterns and make some projections based on some basic characteristics.

4.1.1 Deforestation in the Legal Amazon

PRODES project generates information on deforestation for the Legal Amazon since 1988. This yearly information is used by the Brazilian government to define public policies within the Legal Amazon. According to PRODES (2018) Deforestation in the Brazilian Amazon was increasing between 1998 and 2004. This increase is evident in

Figure 20.

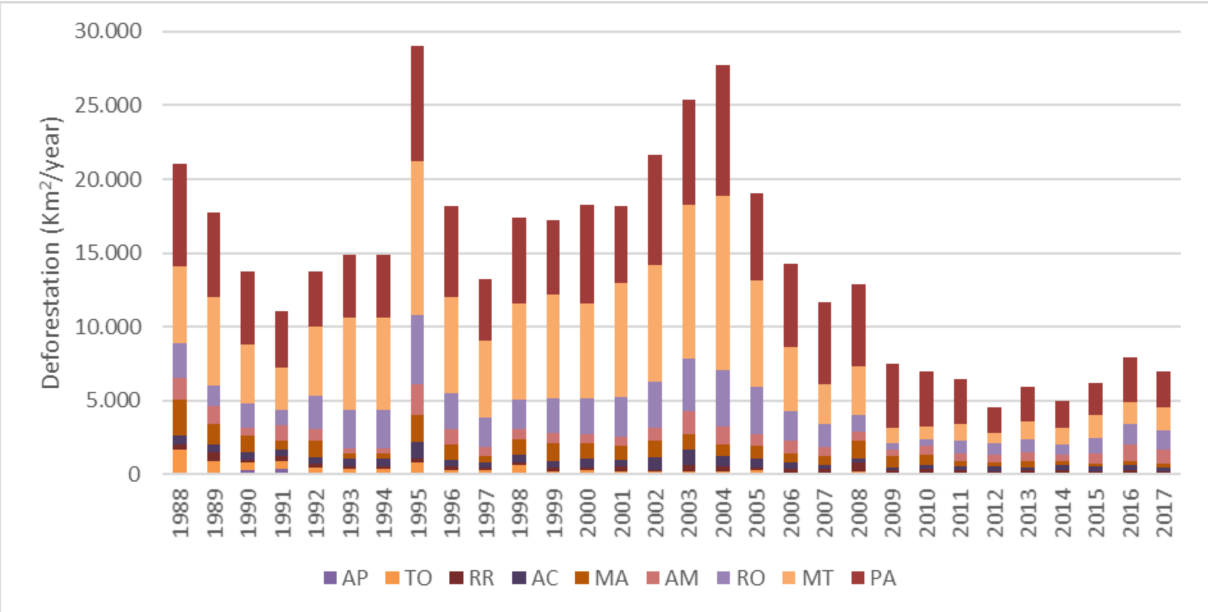


Figure 20: Total deforestation in Brazilian Legal Amazon, by federal unit, 1988-2017. Km²/year.

Source: elaborated from PRODES (2018).

Figure 20 shows how deforestation was doing up to 2005. We can see that the amount of forest area being cleared was positive and growing between 1997 and 2004, with a reduction in 2005.

According to governmental data, in 2004, 16% of the Legal Amazon was already deforested, accounting for 670.000 km^2. Between 1996 and 2005, estimated growth rates using linear, logistic and logarithmic models showed that deforestation rates would continue to increase. Government estimated 19.625 km^2/year, as mean deforestation for the same period. By 2020, deforestation rates could have been 25.767 km^2 (logarithmic), 38.850 km^2 (linear) and 50.604 km^2(exponential)[19], using 1996-2005 data. This situation was unsustainable, and an action needed to be taken urgently to prevent de loss of the Amazon biome. In 2003, the government initiated a task force (Grupo Permanente de Trabalho Interministerial), under supervision of the Presidency and the Ministry of Environment, to address the issue. In 2004 was promoted the Actıon Plan to Prevent and Control Deforestatıon ın the Legal Amazon (PPCDAm). Between 2004 and 2011 it was carried out the first and second stages of the Action Plan. Between 2012 and 2015, it was carried out the third phase. The fourth phase is developed between 2016 and 2020.

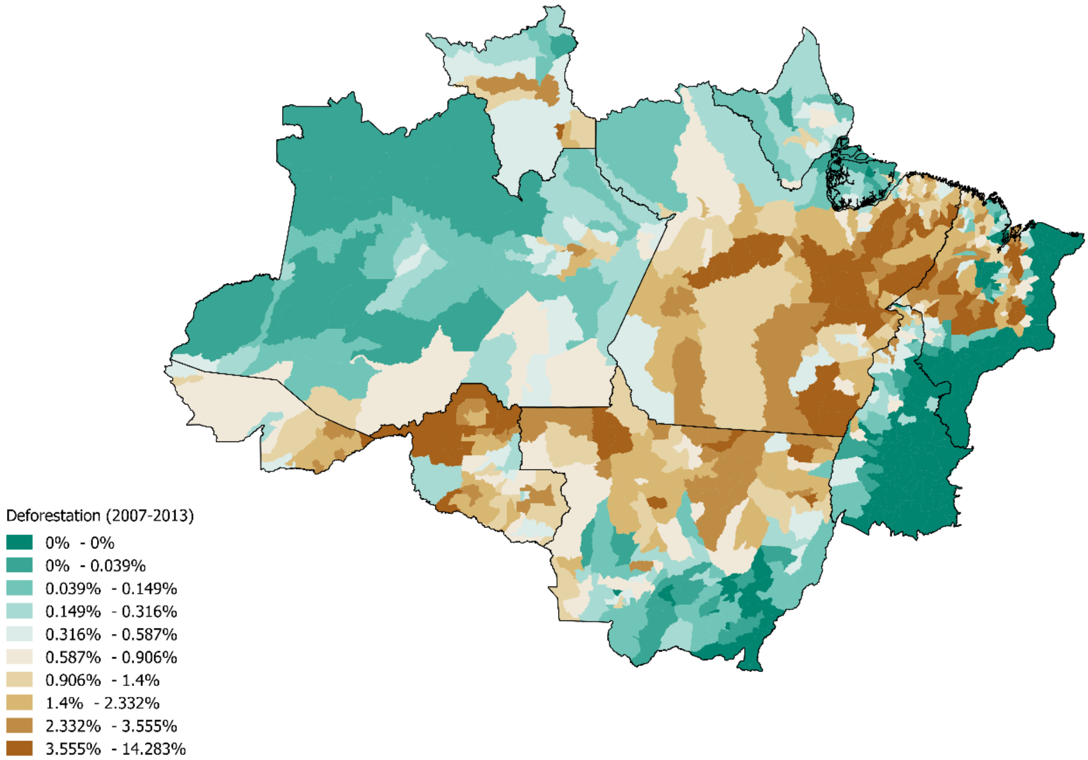
Impact of the implementation of the PPCDAm action plan can also be seen in

Figure 20. Deforestation reduced between 2004 and 2012. After 2102, deforestation increase again. Federal Units (FU) with highest share on deforestation in 2004 were Mato Grosso, Pará and Rondônia. Each one of these FU had a share of 41,8% (622.000 ha), 28,8% (428.400 ha) and 17,4% (259.500 ha), respectively. For 2017, share on deforestation reduced for Mato Grosso with 22,5% (156.100 ha) and increased for Pará 35% (243.300 ha) and Rondônia 17,9% (124.300 ha). We can see that share Pará is the most deforested FU throughout the historical data. FUs are increasing their share on deforested area on 2017 when compared with 2004. Amazonas goes from 4,4% (123.200 ha) to 14,4% (100.100 ha), Acre goes from 2,6% (72.800 a) to 4,8% (27.900 ha), Maranhão started with 2,7% (75.500 ha) and ended with 3,7% (21.700 ha), and Roraima started with 1,1% (31.100 ha) and ended with 2,5% (14.800 ha). This increase on the share of other FU show a structural change in the way deforestation is being distributed along the Legal Amazon: total deforestation is reducing but share is spreading, new areas are being incorporated, but traditional deforestation areas keep important participation.

Barreto et al. (2008) demonstrated that reduction on deforestation rates are related with decrease in beef and soybean prices, and creation of protected areas along the BR-163 highway corridor, soybean moratorium and enforcement activities by the government.

[19] Logarithmic model: $y = 3595*\ln(x) + 14195$, $R^2 = 0.3859$. Linear model: $y = 985.89*x + 14203$, $R^2 = 0.4952$. Exponential model: $y = 14644*e(0.0496*x)$, $R^2 = 0.5092$.

Young, Sant'Anna and Aguiar (2015) state that the region still loses a significant amount of forest cover due to land use change, especially in the agricultural frontier, even in the presence of deforestation reduction from 2005. They showed that there is a clear concentration of deforestation in Southern and Eastern Amazon, corresponding to the "deforestation arc". One important characteristic of these areas is that "they show the expansion of agriculture activities, mainly cattle ranching, and roads and other infrastructure investments that induce the conversion of native forests into other land uses". This results can be seen on map 14



Map 13: Deforestation rate (cum 2007-2013) as a share of total municipality area

Source: Young, Sant'Anna and Aguiar (2015).

Map 13 also show that between 2007 and 2013, deforestation was highly concentrated in a few municipalities: only 27 municipalities were responsible for 50% of total deforestation in 2013, and only four municipalities - Porto Velho, Altamira, São Félix do Xingu and Itaituba - added 1,000 km2 (or 18.8% of total deforestation) in that year. Young, Sant'Anna and Aguiar (2015) state that deforestation is associated to economic and social conditions. In particular, "migration is a key issue, since it changes the occupation of the territory. Traditionally, the Brazilian Amazon is a region of low demographic density. However, infrastructure improvements, especially road construction, and economic incentives to agricultural production, mainly cattle ranching, has changed the demographic balance, with considerable expansion of human activities in the ‘deforestation arc´”.

Some of the main causes of deforestation in the Brazilian Amazon are (Moutinho, 2009): a) conversion of forested area to agriculture or cattle ranching; b) mining; c) wood extraction; d) forest fires. May, Millikan and Gebara (2011) point that some of the historical drivers of deforestation are related with: a) construction of highways to promote “integration” of the Amazon region, b) land allocation to promote small farmer colonization schemes, c) incentives to clear forests as proof of ‘productive’ activity to access public credits, d) conventional models of Amazonian development, to offer new economic opportunities to powerful lobbying groups (specially large cattle ranching), e) creation of infrastructure investment programs to promote export oriented multimodal transportation corridors. For recent deforestation drivers we have: a) forest clearing promoted by land grabbing, to have (illegal) fraudulent access to land titles; b) spatial mobility of illegal logging; c) linked to globalized markets for beef, hides, timber, soybeans, biofuels and other commodities; d) government policies promote deforestation, in particular, in the electrical energy, transportation and agribusiness sectors; e) access to natural resources by through highway construction.

For the Brazilian Ministry of Environment, deforestation in the Legal Amazon relates with expansion of the agriculture frontier in order to answer to specific demands for agricultural product (mainly beef and soybean) from the center-southern states (MMA, 2013). Northern and center-eastern states have increased their herds, mainly Pará, Rondônia, Acre and Mato Grosso. This situation shows that cattle ranching activities are moving to northern states, and this constitutes an important indicative of cattle ranching influence on deforestation. Angelsen et al. (2013) also connected cattle ranching with deforestation: deforestation trends in the Brazilian Amazon are linked to different globalized markets such as beef, hides, timber, soybeans, and other commodities. This situation is also true for Cerrado biome,

One of the five main causes that influence deforestation in Cerrado biome, which also belongs to the Legal Amazon are: extensive cattle ranching is expanding to Permanent Preservation Areas and to Legal Reserve areas (MMA, 2011); also, planted pastures (54 Mha) and agriculture crops (22 Mha) occupied previously forested areas by 2002.

4.1.2 GHG emissions from deforestation in the Legal Amazon

Table 12 and figure 22 shows a description of the evolution of GHG emissions in Brazil by sectors according to Brazilian government report.

Table 11: Brazilian GHG emissions by sectors and gases, 1990-2015. $MtCO_2eq$.

Sector	1990	1995	2000	2005	2010	2015	Var. 1995-2005	Var. 2005-2015	Var. 2010-2015
Energy	187	225	286	316	375	449	40,44%	42,09%	19,73%
Industrial processes	52	65	74	78	90	95	20,00%	21,79%	5,56%
Agriculture	287	317	328	392	407	429	23,66%	9,44%	5,41%
Land Use Change and Forestry (LUCF)	792	1.931	1.266	1.905	349	332	-1,35%	-82,57%	-4,87%
Waste disposal	28	33	40	47	53	63	42,42%	34,04%	18,87%
Total	**1.346**	**2.571**	**1.994**	**2.738**	**1.274**	**1.368**	**6,50%**	**-50,04%**	**7,38%**

Source: adapted using data from MCTI– SEPED– CGCL (2017) and MCTI (2018)

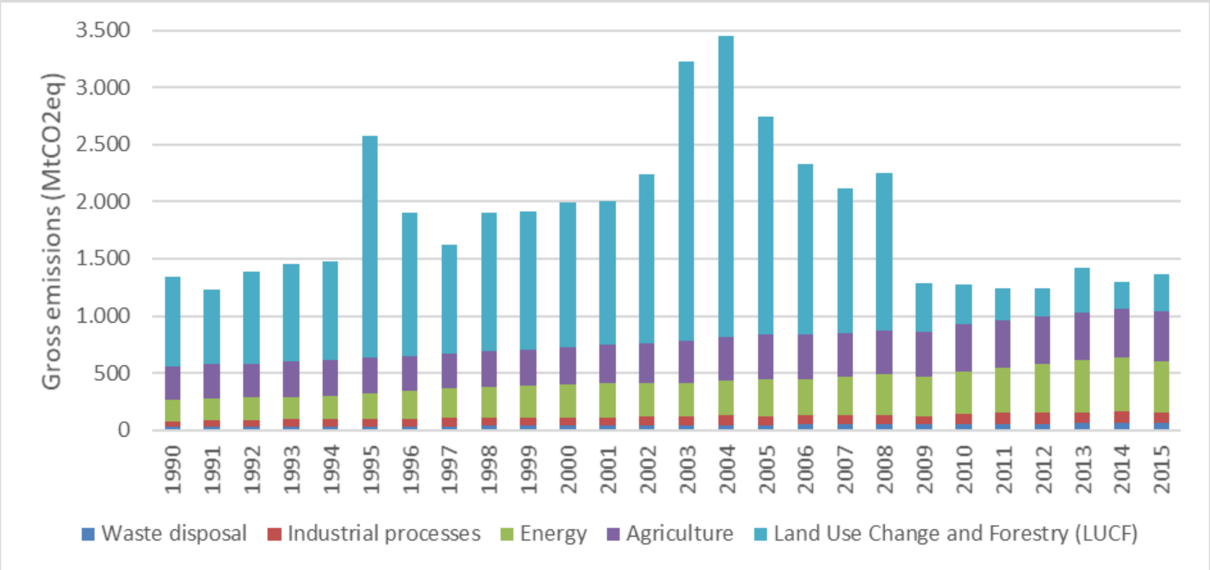


Figure 21: Total Brazilian GHG emissions by source, 1990-2015 in $MtCO_2eq$.

Source: adapted using data from MCTI– SEPED– CGCL (2017) and MCTI (2018)

Table 11 and Figure 21 show that Brazil has been reducing its total GHG emission. According to the Brazilian Ministry of Science, Technology and Innovation (MCTI), emission grew 6,5% between 1995-2005 and -50,04% between 2005-2015. For Climate Observatory (SEEG, 2018), this growth was somehow different: 17% and -36% respectively[20]. For MCTI, Land Use Change and Forestry (LUCF) was the main source of reduction, with a total reduction of 82% between 2005 and 2015. In 1990, main contribution to Brazilian GHG emission was generated in LUCF (59%), followed by agriculture/cattle ranching (21%) and energy (14%). In 2015 the main contributing sector is still LUCF but with a smaller participation (24%), while agriculture (31%) and energy (33%) participation have risen. What we are witnessing is an important process of change in the development model. While, traditionally, Brazil based its growth on agricultural commodities, like cattle, soybean and sugarcane, today, the new needs of an increasing urban population and an expanding middle class, requires new energy sources. In the energy sector, fossil fuel combustion accounted for 95% of the total emissions, and fugitive emissions accounted for the remaining 5%, between 1990 and 2015.

The other sector that showed an important increase was industrial processes. It showed an increase of 28% and 21% for the 1995-2005 and 2005-2015 periods. Production of iron, steel and pig iron accounted for 47% of emission in the industrial sector in 1990 and 41% in 2015. Cement production accounted for 21% in 1990 and 25% in 2015 of industrial sector emissions. These two sectors are very important providers of inputs for infrastructure generation, like roads, buildings, bridges and other mobilization facilities (airports and bus stations). Brazil is having a new boom on construction: 2014 World Cup, and 2016 Olympics, generated a new dynamic in the building sector, including also private sector, i.e.: hotels, ports, railroads. This economic model based on credit, consumption and commodities is following the Chinese model to invest on infrastructure (Credit Suisse 2013).

This structural change on GHG emissions means that Brazil is going to a reprimarization process: despite the important GHG emissions reductions between 2005 and 2010, Brazil is heavily investing in mining, oil and gas drilling, agriculture, and hydroelectric power, to increase exportations, accompanied by a reduction of requirements by land use legislation in 2012 (Toni, 2015). In fact, Young (2015), showed that in order to move Brazilian economy to a long term transition to a green economy it is important to encourage activities with higher

[20] Climate Observatory is a group of NGO's that generate a complete time series data for Brazilian states and sources, since 1970 up to 2016. Every 5 years Ministry of Science, Technology and Innovation (MCTI) generate official statistics on GHG emissions, starting in 1990. Today, there is and new system called National Emissions Registry Systems (SIRENE) that is generating yearly information, up to 2015. There is not report for 2016 available yet. For information on governmental statistics, see MCTI– SEPED– CGMC (2017) and MCTI (2018).

innovation and less pollution effects, like biofuels, wind power and protected areas, instead of the current trend of specialization on primary goods and "dirty" industrial commodities.

Table 12: Brazilian Land Use Change and Forestry emissions, 1990-2015. Millions of tons CO_2eq.

Sector	1990	1995	2000	2005	2010	2015	Var.1995-2005	Var.2005-2015	Var.2010-2015
LULUCF	**792.035**	**1.931.482**	**1.265.608**	**1.904.665**	**349.177**	**331.806**	**-1,39%**	**-82,58%**	**-4,97%**
Land use alterations	786.932	1.926.087	1.256.891	1.897.191	338.753	318.324	-1,50%	-83,22%	-6,03%
Amazon	461.978	1.526.541	857.493	1.184.958	179.824	88.432	-22,38%	-92,54%	-50,82%
Cerrado	249.632	227.128	227.051	301.380	66.791	89.720	32,69%	-70,23%	34,33%
Mata Atlântica	27.274	120.197	120.146	356.153	79.710	127.962	196,31%	-64,07%	60,53%
Caatinga	29.323	25.411	25.400	16.549	-2.902	-3.072	-34,87%	-118,56%	5,86%
Pampa	18.862	22.877	22.870	22.703	2.913	2.867	-0,76%	-87,37%	-1,58%
Pantanal	-137	3.933	3.931	15.448	12.417	12.415	292,78%	-19,63%	-0,02%
Liming	5.103	5.395	8.717	7.474	10.424	13.482	38,54%	80,39%	29,34%

Source: Adapted using data from MCTI– SEPED– CGCL (2017)

Between 1990 and 2015, Land Use Change and Forestry was the sector that generated highest contributions to Brazilian GHG emissions. Table 12 shows that land use alterations, an activity totally related with deforestation, accounted between 96% and 100% of total emissions for this sector, between 1990 and 2015. Amazon biome generated most deforestation emissions (59% in 1990 and 28% in 2015) followed by Cerrado biome (32% in 1990 and 28% in 2015).

According to PR-CS-GPTI (2004), cattle ranching activities were responsible for 80% of the deforested area in the Legal Amazon. In addition, they recognize other deforestation factor like soybean expansion, deforestation in public lands and land grabbing (*grilagem de terras*), illegal logging, infrastructure investments (mainly highways), new human settlements in isolated areas, internal migration because of rural poverty and land speculation.

4.1.3 Cattle ranching future land use: projections for agribusiness

In 2016, the Brazilian Ministry of Agriculture generated prospective estimates of sectorial agribusiness production by Federal Unit, as a basis for strategic planning. These estimates are based on assumptions on demand, supply, trade, commodity prices, macroeconomic and sectorial policies. Government generated production estimates for the 2015-2025 period, and we generated and additional 5-year period to complete a production projection up to 2030. In

Annex 8 there is a complete set of projections for agriculture by type of product and Federal Unit.

Total agricultural area in Brazil (pastures plus temporary and permanent agriculture) is expected to grow form 283 million hectares in 2015 to 341 million hectares in 2030 (Figure 22). This represents a 1,34% mean annual growth.

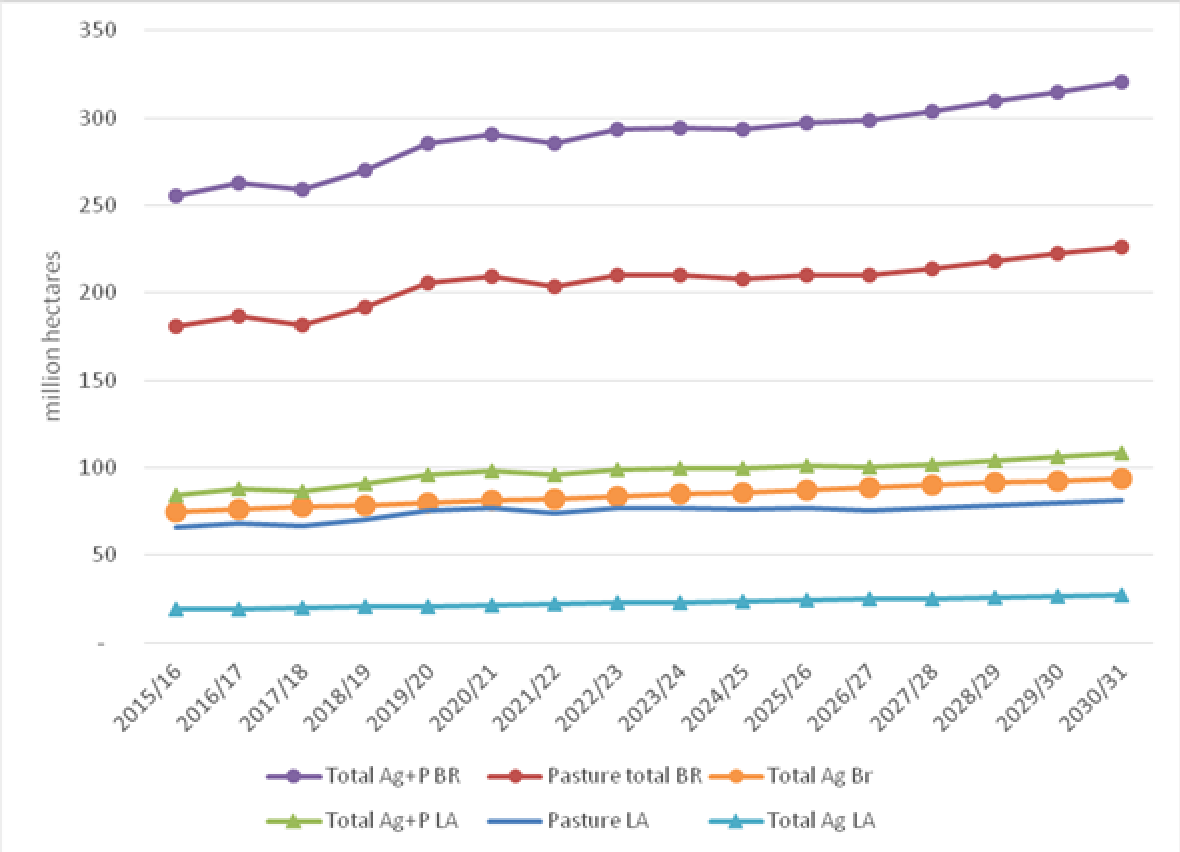


Figure 22: Agriculture and pastures expansion for agribusiness in Brazil and Legal Amazon. 2015-2030

Source: 2015-2025 adapted from MAPA-SPA (2016). 2015 -2030, author's calculations.

For the whole country, pastures share 74% of total area, it is estimated that it will reduce its share to 72% in 2030, even though it will have a 1,22% mean annual growth. For the Legal Amazon, a similar situation is expected: total agricultural area will grow from 96.6 million hectares in 2015 to 117.5 million hectares in 2030. This represents a 1,4% mean annual growth, which is slightly higher than the country annual growth. Pastures share 81% of total area in 2015 and it is expected to share 77% of total area by 2030, with an associated 1,08% mean annual growth. Agricultural activities in the Legal Amazon will present a higher mean annual growth for the same period: 2,62%, which in turn is higher than the overall country mean annual growth (1,66%). Government projections (up to 2025) and 2030 production estimates, show that cattle ranching activity will continue to be the most important land use activity in LA, although agricultural crops will tend to increase their participation and growth in LA and the whole country.

Total pasture area in LA is approximately 37% of total pasture are in the country. In turn, this area is almost as big as total Brazilian temporary and permanent agricultural area, sharing 27% of total Brazilian agricultural area.

Total pastures expansion was projected using government estimates of beef production. We projected total carcasses weight, mean cattle weight when slaughtered and finally total estimated cattle herd. With these estimates, it was possible to determine total pasture area using cattle stocking rates.

Estimates using linear and logarithmic models are shown in the following Figure 23 and Table 13 for 2006-2015 and 2015-2030.

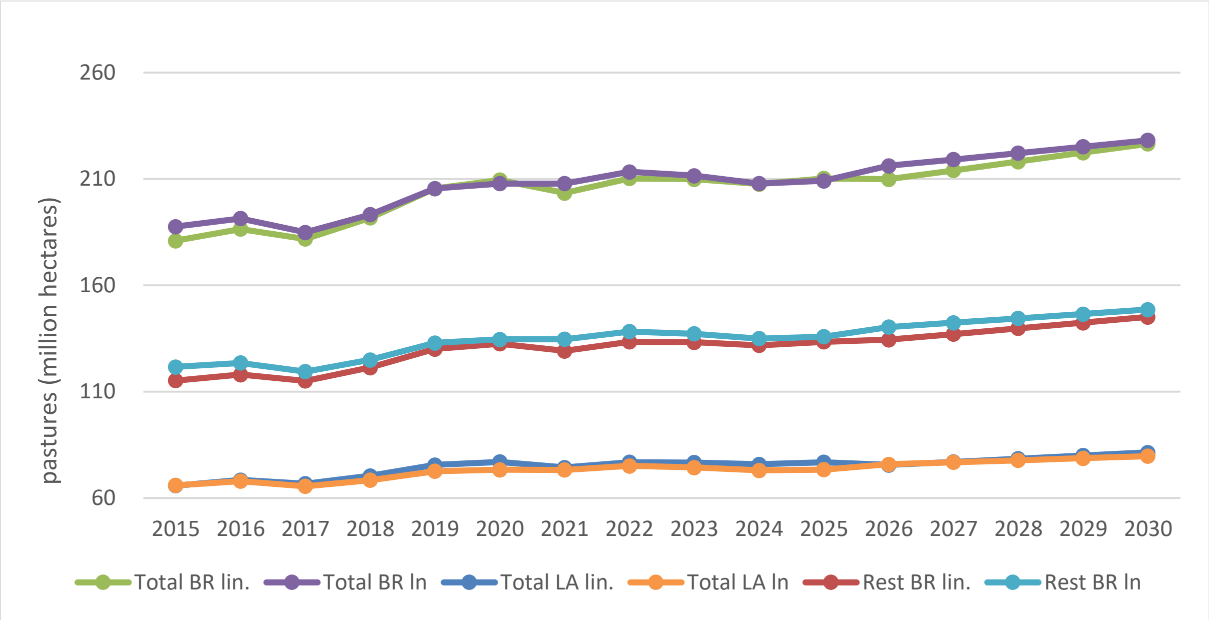


Figure 23: Pastures area expansion in Brazil and Legal Amazon.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author’s calculations.

Table 13: 2006-2015 and 2015-2030 pasture area projection using linear and logarithmic models.

Area	2006/2015 (lin)		2006/2015 (ln)		2015/2030 (lin.)		2015/2030 (Ln)	
	Area increase	Period growth	Area increase	Period growth	Area increase	Period growth	Area increase	Period growth
Total AL	3.153.030	5,0%	3.339.841	5%	15.635.700	24%	13.690.157	21%
Rest BR	3.863.440	3,5%	10.285.694	9%	29.945.075	26%	26.944.643	22%
Total BR	7.016.470	4,0%	13.625.535	8%	45.580.775	25%	40.634.800	22%

Source: 2006-2015 data from IBGE, 2015-2025 adapted from MAPA-SPA (2016), 2025 - 2030, author's calculations.

Previous figure and table show that pastures area increase between 2005 and 2015 was higher in Legal Amazon states (5% to 6%) than in the rest of Brazilian states (4% to 9%). For 2015 to 2030 projected period, expected pasture area in Brazil will be driven by expansion of non-Legal Amazon states: expected growth rate for the whole period will be between 22% to 26%, while Legal Amazon states will show a total area growth rate between 21% to 24%.

The following figures shows projected pasture's area expansion by Federal Unit.

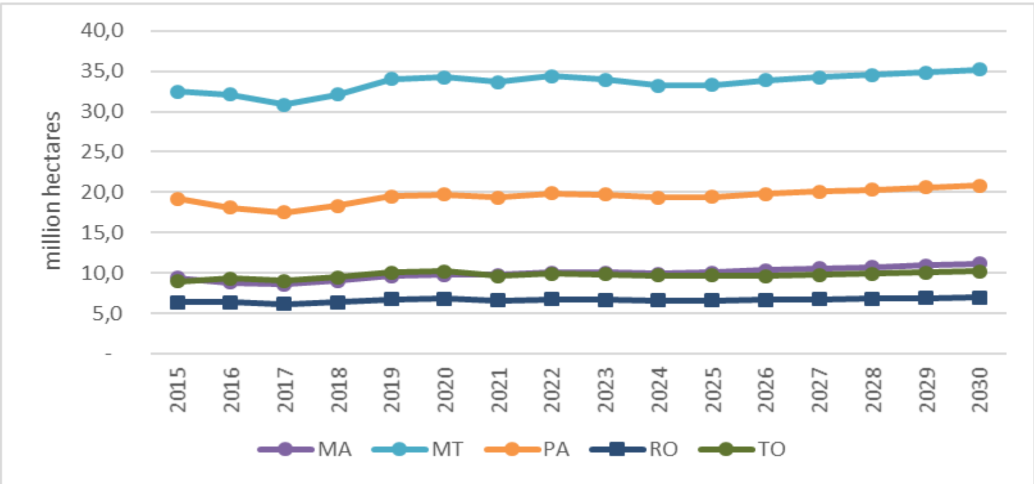


Figure 24: Pastures area expansion in LA states (I). 2015-2030. Lineal growth.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations

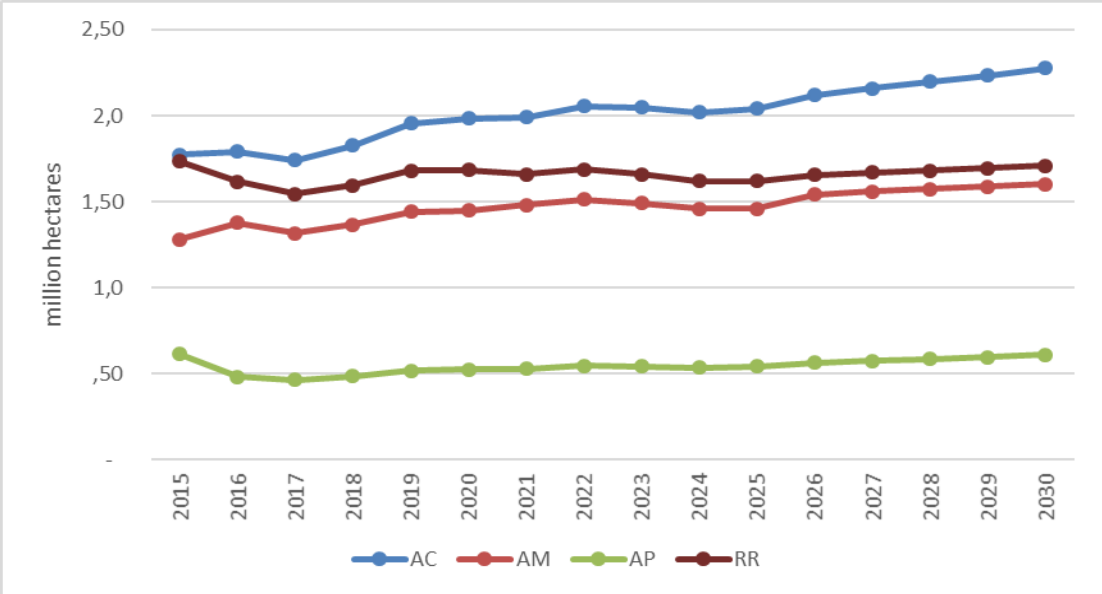


Figure 25: Pastures area expansion in LA states (II). 2015-2030. Lineal growth.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

Figure 24 and Figure 25 show that Mato Grosso and Para account for almost 55 million hectares of pastures up to 2030 (nearly 37% of total LA pastures area). In 2015 these two states account for 42% of total pastures' area. We will be witnessing an expansion of forest areas in other states, as other states start to increase their share in 2030.

Acre, Amapa, Amazonas and Roraima federal units' account for the lowest share of pastures expansion. This situation is showing that consolidated areas for cattle ranching continue to have a high important share of total pastures, but new areas will be included, in forest areas that still have areas for agricultural expansion. For example, Acre is expected to show the highest growth, changing from 1,7 to 2,2 million hectares (nearly 30% growth). Acre constitutes one of the federal units with lowest share of pastures, along with Amazon, but with increasing development of infrastructure (highways), along with Amazonas and Rondônia. Municipalities in these federal units constitute expansion areas, where some "frontier" forests are found (se maps of forest transition theory in next section).

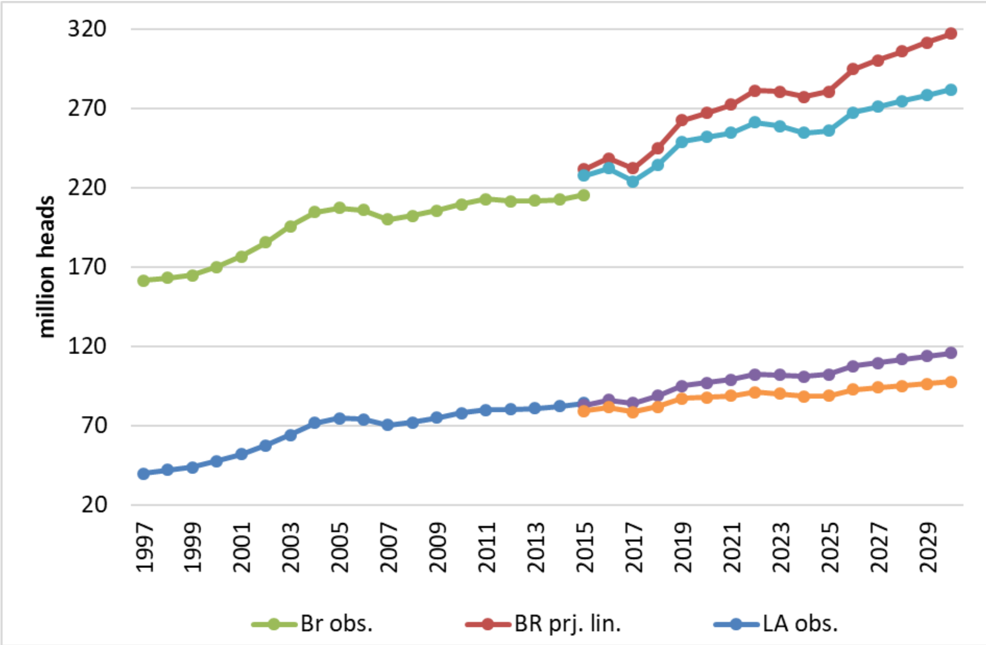


Figure 26: Observed (1997-2015) and projected (2015-2030) cattle heads for Brazil and Legal Amazon, using linear and logarithmic projections.

Source: for 1997-2013, IBGE (2014) PPM, and 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

Total increase of projected cattle herd shows particular trends (Figure 26). For observed heard between 2006 and 2015, in Legal Amazon, growth rate was 12,4%, with a total share of 39,1% in 2015. Total Brazilian herd growth for the same period was 4,3%. For projected cattle herd, there is an important change for Legal Amazon: total period growth rate will be 18,8%, with a reduction in total Brazilian herd share to 34,6%. From the perspective of government, there is a clear intention to promote higher growth rates in non-Legal Amazon states, in order to comply with projected beef production and exports. The main question is where are these areas coming from? Are they coming from additional deforestation of from increasing intensive use of other agricultural activities, allowing agricultural area's liberation for pastures?

According to MAPA-SPA (2016), total beef consumption will increase from 6,6 million tons in 2016 to 7,7 million tons in 2026 (16,56% growth). Exports will increase from 1,91 million tons in 2016 to 2,6 million tons in 2026 (36,19%). This is an important driver that explains expected pastures and cattle herd growth.

Figure 27 shows projected cattle heard by Federal Unit.

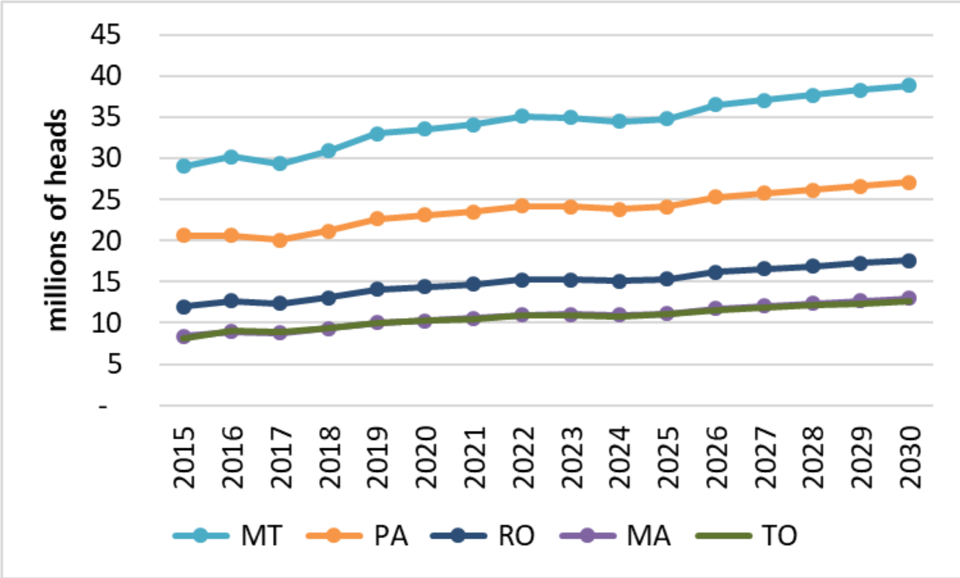


Figure 27: Projected total cattle heard by Federal Unit in the Legal Amazon (MT,PA, RO, MA & RO)

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

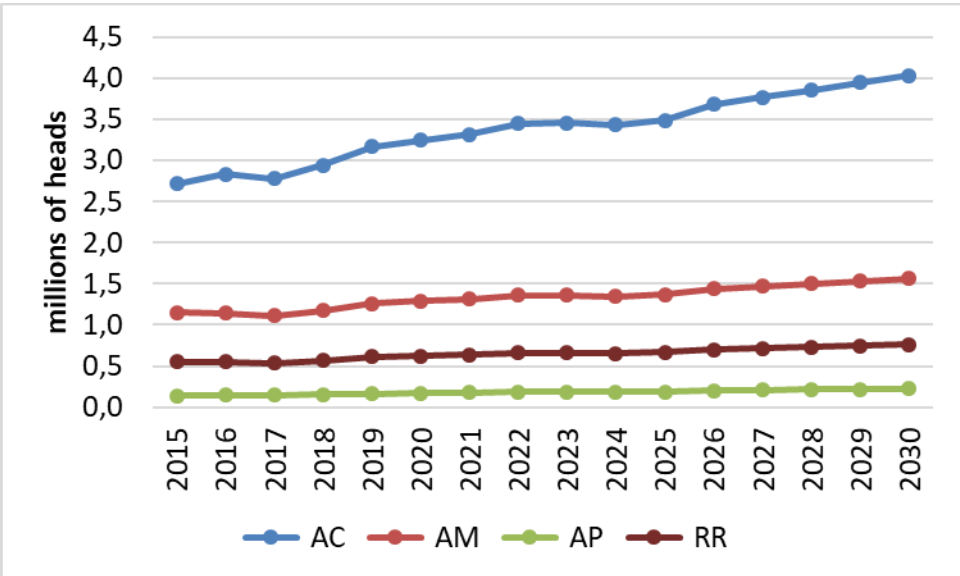


Figure 28: Projected total cattle heard by Federal Unit in the Legal Amazon (AC, AM, AP & RR)

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

In Legal Amazon, Mato Grosso, Pará and Rondônia concentrate the highest cattle herd, sharing nearly 73% of total heard (Figure 27). Highest growth rates are expected to occur in Maranhão (31%), Acre (30%), and Pará (28%) (Figure 27 and Figure 28). These states have a low share of total cattle heard in Legal Amazon, so what this data shows is, that areas that once had low cattle population will start to increase their herd, generating additional pressure on forests and natural ecosystems.

Pasture area expansion is related to cattle herd expansion, through cattle stocking rates. Table 14 shows observed and projected stocking rates.

Table 14: Observed and projected stocking rates Legal Amazon states, other states and Brazil. 1996, 2006, 2016, 2021 and 2026.

Federal Unit	1996	2006	2016	2021	2026
AC	1,39	1,84	1,76	1,89	1,97
AM	1,39	0,68	0,85	0,79	0,75
AP	0,26	0,25	0,25	0,27	0,27
MA	0,74	1,09	1,03	1,15	1,22
MT	0,71	1,13	1,08	1,16	1,23
PA	0,89	1,30	1,38	1,49	1,60
RO	1,36	2,18	2,49	2,92	3,22
RR	0,23	0,41	0,41	0,41	0,43
TO	0,53	0,81	0,92	1,14	1,25
Total LA	0,74	1,18	1,21	1,33	1,42
Rest BR	0,95	1,19	1,26	1,34	1,39
Total BR	0,89	1,19	1,24	1,34	1,40

Source: 1996 and 2006 data from IBGE (2014). 2016-2026 adapted and projected from MAPA-SPA (2016).

Mato Grosso, Para and Rondônia states show the highest herd participation and the highest pasture areas share in the Legal Amazon. These federal units also present highest stocking rates.

We projected cattle ranching stocking rates from historical information for each federal unit. Previous tables show an interesting fact: stocking rates grew 59% for Legal Amazon states, 25% for non-Legal Amazon states and 34% for whole country, between 1996 and 2006. Projected stocking rates assumed a conservative approach, with 20%% projected growth for

Legal Amazon states, 16% for non-Legal Amazon states and 17% for the whole country, between 2006 and 2026.

4.1.4 Dependence of cattle ranching growth on deforestation: induced innovation

In a previous section, we review Reis (2016) analysis on stocking rates' evolution for the period 1975-2005. For the period 2015-2030, we made some calculations on the decomposition of stocking rate. The following figures show these results for the LA and for each state that belongs to the LA.

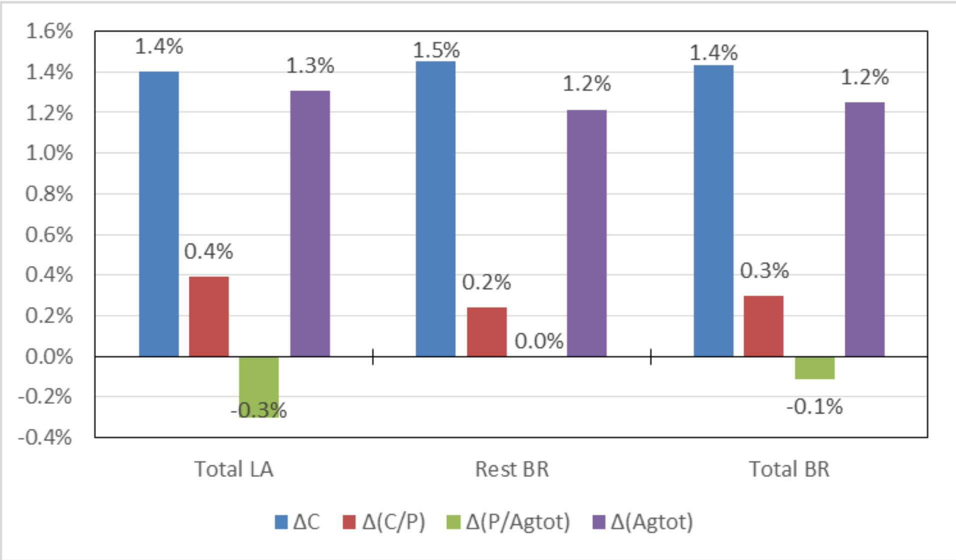


Figure 29: Cattle herd growth by main components Brazil and Legal Amazon, 2015-2030.

Source: 2016-2026 adapted and projected data from MAPA-SPA (2016).

Figure 29 shows that in Legal Amazon, expected growth of cattle herd (ΔC) is supported mainly by expansion of the agricultural area (ΔAgrtot). The increment on stocking rate (Δ[C/P]), that is the demand of land for each head of cattle, is almost offset by the reduction of present supply of available grassland (Δ[P/Agtot]) in comparison to increase in the supply of present total agricultural land. The net result is a growing herd, with stocking rates growing very little, at lower rates than the total herd growth. This finally happens only because deforestation area grows slower than the total herd growth. A similar situation occurs in non- Legal Amazon states and in Brazil as a whole: cattle herd grows at the expense of little increase in the stocking rates and high expansions of forest area.

For the Legal Amazon states, we found additional results, while analyzing data per state.

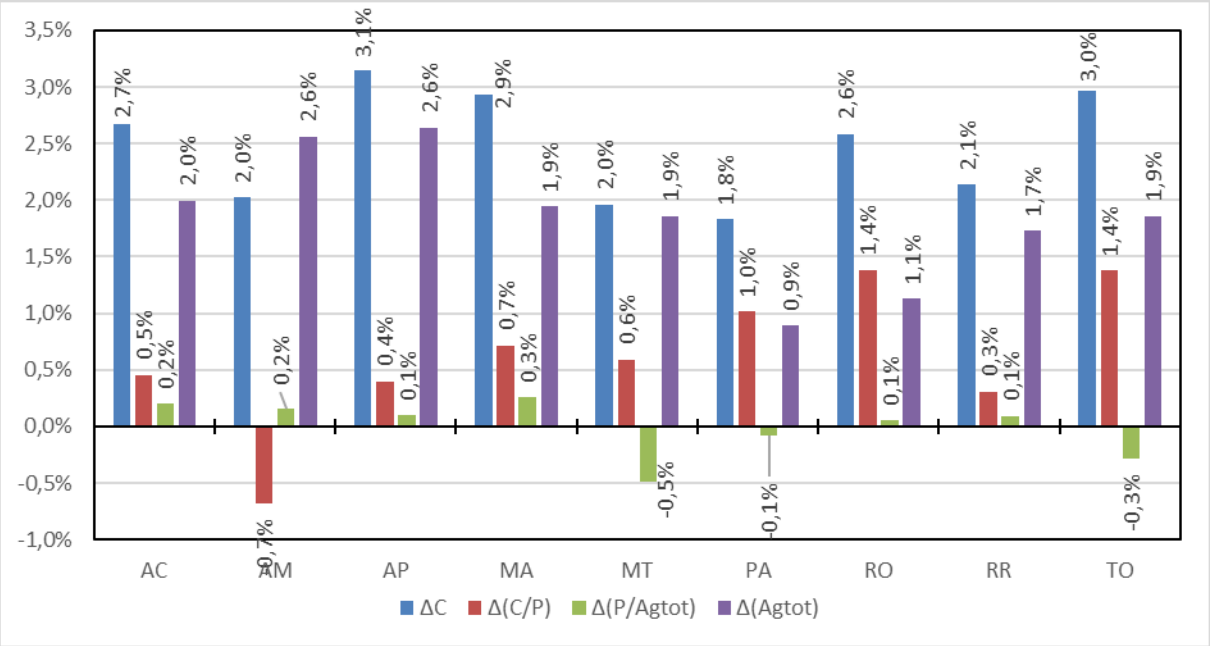


Figure 30: Cattle herd growth by main components for Federal Units of Legal Amazon.

Source: adapted and projected data from MAPA-SPA (2016).

For the Amazonas state, it is clear that the cattle expansion will be based on reducing grazing ratios and an expansion of deforestation that exceeds herd growth (Figure 30). In contrast, Para, Roraima and Tocantins states will show the highest changes in stocking rates. There is a small effort to have a higher amount of pastures over agriculture area in Acre, Amapá, Maranhão and Mato Grosso, and the highest efforts on increasing stocking rates will be found in Para, Rondônia, and Tocantins. Anyway, none of the LA states show a stocking rate growth higher than herd growth. Roraima, Tocantins and Maranhão have the highest differences between herd growth and deforestation growth. Therefore, these states will have less dependence on deforestation.

4.1.5 Key performance indicators

Selected indicators for identifying the BAU and SEM scenarios are the following:

- Deforestation and reforestation (forest remnants)
- GHG emissions.

Deforestation and reforestation rates are key to understand evolution of Land Use Changes throughout time. Deforestation is a very important indicator because it is being directly monitored by several government organizations, in particular by Spatial Research National Institute (INPE). In addition, it has specific international government commitments: during 2015, Brazil presented it´s Intended Nationally Determined Contributions (INDC), and as part of this commitments, a zero illegal deforestation target was set for 2030[21]. It is important to remember that the initial date for zero illegal deforestation was previously set to2015. In addition, the Legal Vegetation Act (Lei 12651/2012) set a 12 million hectares' goal for reforestation. For the agricultural sector it was set a goal to restore 15 million hectares of degraded pastures and establish 5 million hectares of integrated cropland-forestry-livestock systems (see chapter on policy analysis).

In terms of GHG emissions, the Government of Brazil established an emissions reduction target of 37%, below 2005 levels by 2025 (1.300 MtCO_2eq) and a 43% reduction target by 2030 (1.200 Mt CO2eq). The establishment of a PES scheme can influence in the achievement of these goals.

4.1.6 BAU scenario

The potential for reducing carbon emissions from forest conservation refers to estimated greenhouse gas (GHG) emissions, notably carbon dioxide (CO_2), which would no longer be released into the atmosphere due to the establishment of a national PES. This component is also known in the literature as Reducing Emissions from Deforestation and Forest Degradation (REDD)[22], and is associated with forest conservation activities.

Avoiding deforestation by promoting forest conservation activities is one of the cheapest and fastest ways to reduce carbon emissions on a large scale. In Brazil, in particular, this strategy is effective, since most of the current emissions of greenhouse gases in the country continue to be caused by deforestation[23], especially in the Amazon and Cerrado biomes.

[21] http://www.wri.org/blog/2015/09/closer-look-brazils-new-climate-plan-indc

[22] REDD + (Reducing Emissions from Deforestation and Forest Degradation) is a set of positive policies and incentives for reducing emissions from deforestation and forest degradation, and increasing forest carbon stocks (including conservation and sustainable forest management) in developing countries (UNFCCC, 2007)

[23] Se the chapter on emissions to understand the change in participation of Land Use Changes against Agriculture and Industry in total Brazilian GHG emissions.

A study by the Ministry of the Environment (MMA 2012b) identified forest conservation as an instrument that can establish policies and incentives to reduce deforestation and forest degradation, recognizing the importance of forest conservation and management, as well as increasing forest carbon stocks. To that end, forest conservation actions should have their effects measured, verified, quantified and demonstrated from at least one of these activities (UNFCCC, 2007):

I. Reduce emissions from deforestation;

II. Reduce emissions of degradation;

III. Preserve carbon stocks;

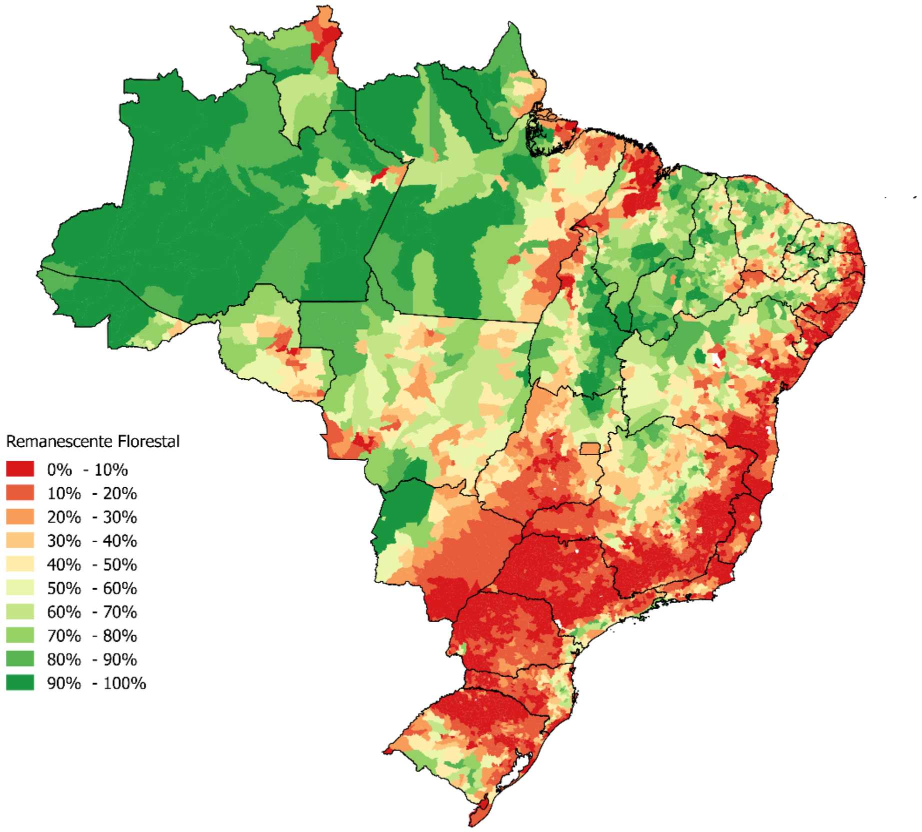
IV. Enable sustainable forest management;

V. Increase carbon stocks.

4.1.6.1 Forest remnants

Establishing a PES for forest conservation, however, requires establishing a baseline for the projection of deforestation, since it would not be correct to assume that every forest area would be converted for agricultural use. That is, the payment should not be made to any forest remnant area, but only to the area that was supposed to suffer the deforestation threat.

In this way, the first step of the modeling consisted in the identification of native forest remnants at the local level (Map 14).



Map 14: Forest remnants as percentage of total municipal area.

Source: own elaboration base on INPE-Prodes (2016) data.

Forest remnants were obtained from information on annual deforestation in each biome. The database "Deforestation Monitoring in the Brazilian Biomes by Satellite - PMDBBS" (MMA) was used, which defines forest remnants and / or average rates of deforestation for all municipalities in Brazil, separated by biomes. The information from the Amazonian biome comes from the PRODES system, organized by the National Institute for Space Research (INPE) (INPE, 2014).

4.1.6.2 Deforestation SISGEMA

It should be emphasized that the model works with aggregated values by municipality. Thus, it does not consider the distinction between illegal deforestation and suppression of native vegetation allowed by legislation. Future studies may better characterize this difference, especially after the information provided by the National Rural Regestry System (SICAR).

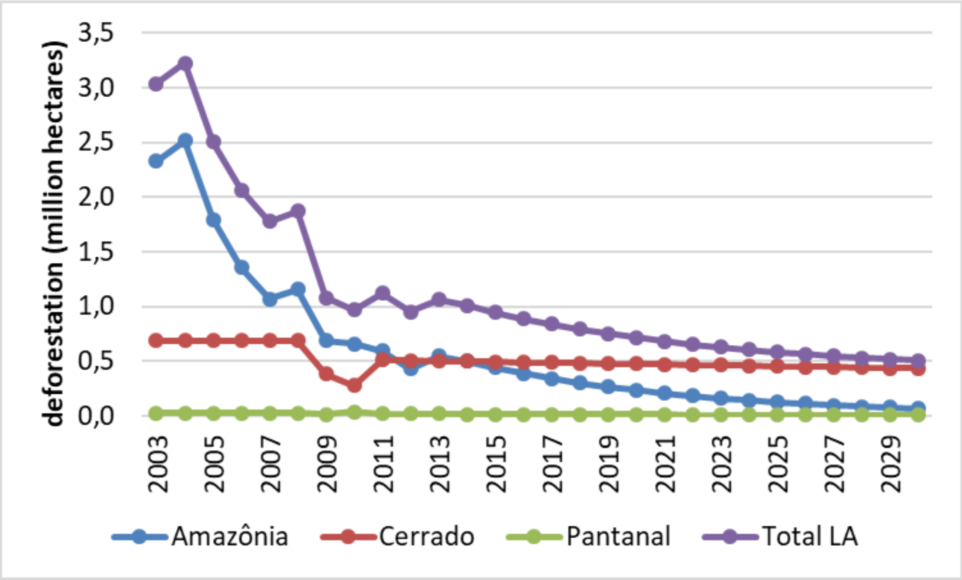


Figure 31: Deforestation projection using SISGEMA, by biomes of Legal Amazon. 2003-2030.

Source: own elaboration based on SISGEMA model results.

Figure 31 show that there has been a significant fall in deforestation in the Amazon biome since 2004, when it had its peak. This success can be attributed to different factors, such as: politicians, increased control and monitoring actions and annual monitoring of PRODES and DETER, and economic, such as changes in agricultural commodity prices and benefits restrictions for municipalities included in the list of major deforestation.

Cerrado biome showed a rate of deforestation in the period 2002-2008 well above the average of other years, with a reduction in subsequent years (2008-2010). The calculation of the deforestation projection reflects this situation: the projection scenario indicates a tendency of small increase for 2011, while the scenario of later years, points to small decline.

Pantanal biome presents one of the smallest deforestations among all the biomes. This can be explained by the difficulty of agricultural production in the seasonally flooded areas of the Pantanal, which makes them less conducive to intensive farming or even intensive livestock farming

Table 15:Deforestation and forest remnants using SISGEMA. Municipalities consolidated by biome. 2003-2030

Biome	Deforestation 2003-2015	Deforestation 2016-2030	Remnant 2002	Remnant 2015	Remnant 2030
Amazon	14.071.254	2.759.357	330.209.209	316.137.955	313.378.598
Cerrado	7.273.482	6.904.651	54.800.649	47.527.167	40.622.516
Pantanal	271.640	123.057	4.646.513	4.374.873	4.251.815
Total Legal Amazon	**21.616.376**	**9.787.065**	**389.656.371**	**368.039.994**	**358.252.929**

Source: own elaboration based on SISGEMA model results.

According to SISGEMA model (Table 15), accumulated deforestation in the Legal Amazon in the period 2016-2030 would exceed 9,7 million hectares, of which the Cerrado would account for more nearly 6,9 million hectares. These results imply a structural change in the biome share on total LA deforestation. While Amazon biome accounted for nearly 66% of total deforested area between 2003-2015, during 2016-2030 it's share was 27%. In contrast, Cerrado biome share during 2003-2015 was 33% and increased to 7,1% for the projected period 2016-2030. Pantanal municipalities have a very low share on total deforestation for both periods (less than 2% of total LA deforestation).

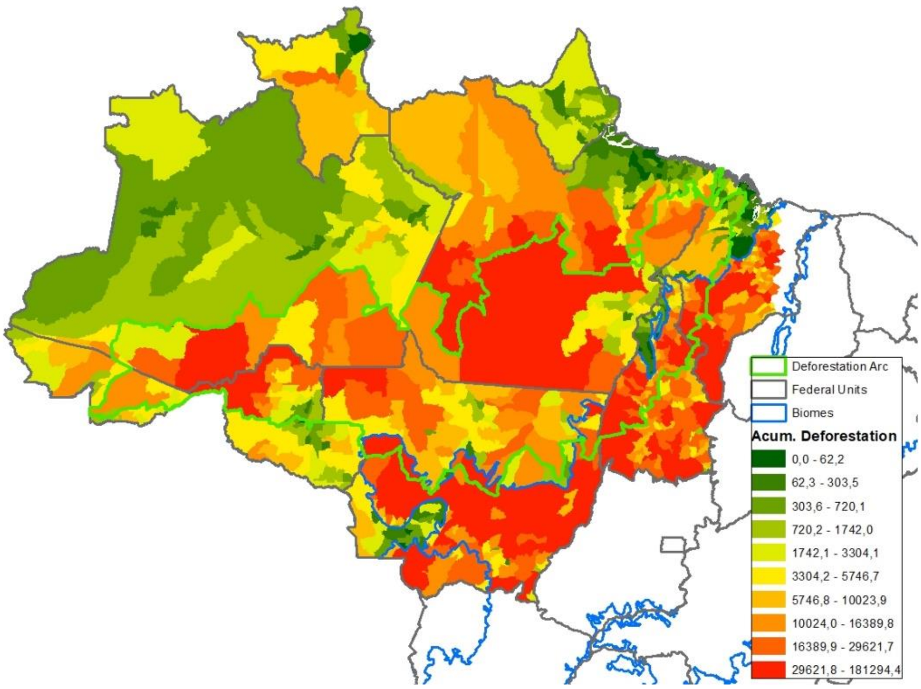
An important trend relates with the possibility of reducing to zero deforestation on 2030. According to our estimates, on a business as usual trend, Amazon biome will reach 65.000 deforestation hectares. For Cerrado biome, deforestation will be around 432.000 hectares. Despite the use of the inverse exponential model, projected deforestation won´t reach a zero point, not for at least 20 more years.

Table 16:Deforestation and forest remnants using SISGEMA. Municipalities consolidated by Federal Unit. 2003-2030

Federal Unit	Deforestation 2003-2015	Deforestation 2016-2030	Remnant 2002	Remnant 2015	Remnant 2030
AC	489.493	106.457	14.885.468	14.395.975	14.289.518
AM	901.301	210.833	144.136.563	143.235.262	143.024.429
AP	79.704	20.362	11.104.963	11.025.258	11.004.896
MA	2.742.961	2.201.550	16.620.467	13.877.506	11.675.957
MT	6.557.126	3.394.376	58.149.882	51.592.756	48.198.379
PA	6.396.746	1.370.686	94.425.953	88.029.207	86.658.522
RO	1.936.436	342.744	14.855.061	12.918.625	12.575.881
RR	320.049	88.724	15.303.448	14.983.399	14.894.675
TO	2.192.561	2.051.333	20.174.566	17.982.006	15.930.672
Total Legal Amazon	**21.616.376**	**9.787.065**	**389.656.371**	**368.039.994**	**358.252.929**

Source: own elaboration based on SISGEMA model results

It is clear that some Federal Units reduced significantly their share, when analyzing municipalities share grouped by Federal Unit (Table 16). Most prominent results are associated with Mato Grosso, Para and Rondônia. A first hypothesis is associated to the forest transition theory: some of the municipalities that lie within these Federal Units are associated to settled areas or frontier areas. An exercise was done to identify frontier, settled or remote municipalities using 2003-2008 deforestation rates and 2005 forest's remnant. One possible future situation is that frontier municipalities end up with some of its remnants, changing its classification to settled municipalities (see Annex 9). Another possibility is that implementation of several policies (i.e. Plan to Prevent Deforestation on Legal Amazon – PCPPDAm), that helped to reduce deforestation continue to generate deforestation reductions in frontier municipalities.



Map 15: Total accumulated projected deforestation (2016-2030) using SISGEMA model by municipality (hectares)

Source: own elaboration based on SISGEMA model results.

The use of the inverse exponential model is not consistent for all biomes in Brazil, since the Amazon biome is the only one that contains information on annual deforestation. For the other Brazilian biomes, the information on deforestation exists for specific periods (for example 2002-2008), requiring its transformation into annual values. This was the case for Cerrado and Pantanal biomes. The exercise of annualized deforestation variation occurring in a given period causes the value to have equal amounts of deforestation, hampering the extrapolation of future deforestation exponential model.

Some municipalities are not included in the reports of deforestation of the respective biome in certain periods of time, appearing in later reports (PRODES / INPE or PMDBBS / MMA). Thus, the construction of a historical series for such municipalities is impaired. In the scenarios of exponential projection, there are municipalities without remnants reported in the years of the historical series, that is, they are already unable to increase deforestation. Therefore, it is not possible to generate deforestation calculation, since there are no more remaining ones. Even in municipalities with information on remnant and deforestation, it is possible that the projection of deforestation exceeds the remnants observed in the municipality. To adjust for this problem, deforestation was extrapolated above forest remnants to nearby municipalities where forest remnants still exist.

Some adjustments were made to correct these problems, creating a maximum deforestation limiter in the municipality. In other words, deforestation cannot exceed the remnant area of the municipality. The biome where the largest difference of the historical average was observed in relation to the exponential deforestation projections in 2030 is Cerrado. This can be explained since the deforestation in Cerrado biome peaked in 2002-2008, which influences the projection for future deforestation.

4.1.6.3 Deforestation using Dinamica EGO

Dinamica EGO allows modeling changes in time and space, changes in land use and other environmental variables. In this way, it allows the development of algorithms for spatial simulations, including transition and calibration functions and validation methods.

Probabilities of deforestation distributed in the study area, supporting the simulations of future land use changes, through the correlation analysis between the past trajectories of selected variables, were estimated following (Mas et al., 2014) and Soares-Filho et al. (2009). With this tool, we elaborated a forecast model for the expansion of deforestation areas for the period 2009-2030.

The transition values between areas of natural remnants for anthropic, deforested or non-forest areas for the whole period (single step) and annualized (multiple step) are presented in Table 17.

Table 17: Transition rates between forest remnants and deforested areas in Brazilian biomes 2002 - 2008.

Biome	Yearly deforestation rate 2002-2008 (single)	Total deforestation rate 2002-2008 (multiple)
Amazon	0.47%	2.81%
Cerrado	1.23%	7.16%
Pantanal	0.55%	3.24%

Source: based on Dinamica-EGO results.

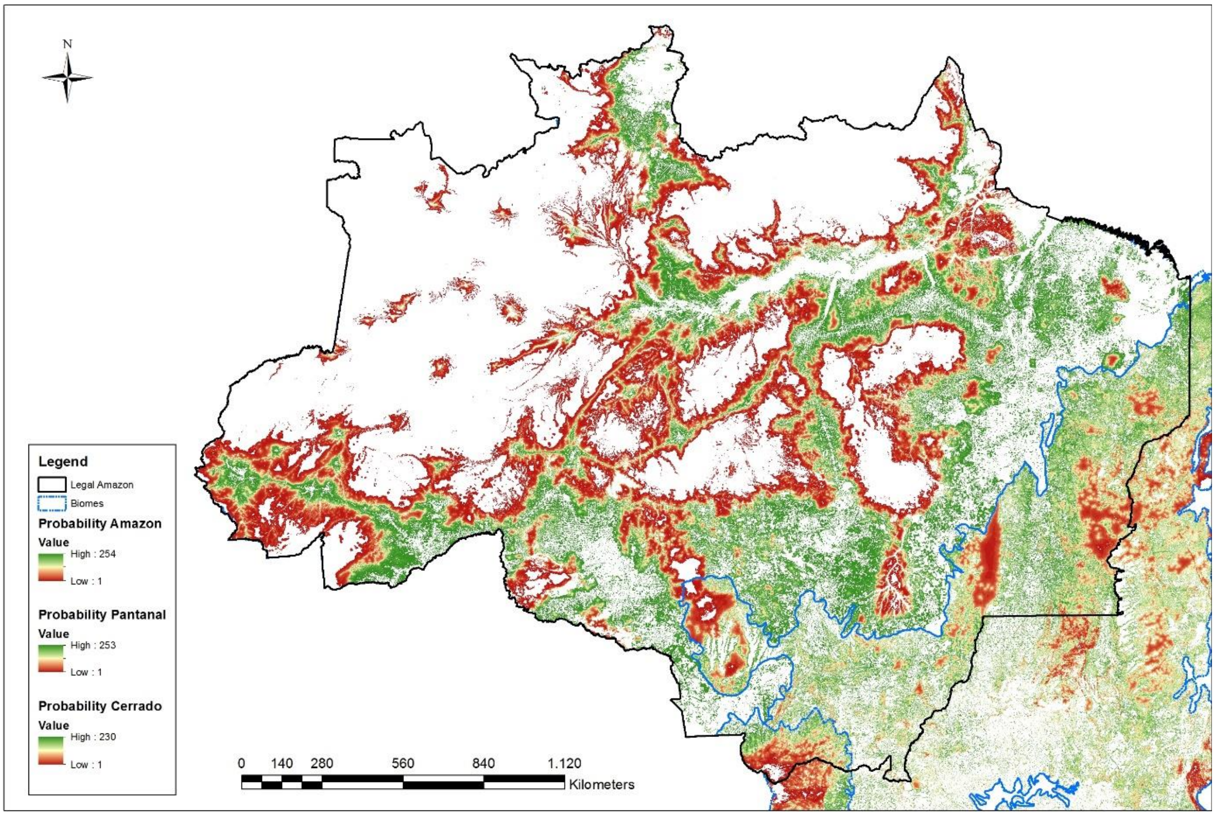
On average, the transformation rate of remnant areas into anthropic areas, used to estimate deforestation, was 4,4% %, considering the entire period 2002/2008 for three biomes, with an annual average of 0.75%. The biome that presented the highest total and annual rates was the Cerrado.

The next step was to analyze the correlation between each of the physical explanatory variables to identify possible correlations, and to exclude those that had a high correlation value. This exercise was done for each of the Brazilian biomes. The variables that presented a joint uncertainty higher than 15% were considered with high correlation, and therefore had to be removed from the set of variables that allow the spatial location of the deforested areas. For example, the variables soil type and protected areas, were removed from the simulation because they showed a high correlation with other variables (joint uncertainty greater than 15%).

After the selection of the variables that did not have a high correlation with the other explanatory variables, the process of adjusting the weight intervals in the spatial location process of the deforestation quantities already quantified from the annual rates of deforestation was performed.

For example, as cities approach areas of forest remnants, their weight increases in explaining deforestation. Similarly, as the remnant areas are further from the cities, the weight of this distance in the probability of deforestation decreases. The weight of this variable in the explanation of deforestation is, therefore, decreasing. Thus, the further away from urban centers, the probability of deforestation decreases.

After calibration of the ranges of the explanatory physical variables, and their weights of evidence, for each of the biomes, a probability map of deforestation was calculated, which basically shows together the probability of deforestation when all relevant spatial variables are considered. The simulation of deforestation between 2002 and 2008 thus generated the maps of probability of deforestation by biome.



Map 16: Legal Amazon deforestation probability.

Source: own elaboration using Dinamica-EGO results.

The areas in red (Map 16) indicate where the probability of deforestation is greater, and the areas in green show areas with low probability, according to the weights of evidence of the different physical variables analyzed. For all biomes, there is a high relation between the probability of deforestation and the distance to forest remnants, with the distance to rivers and roads having an important weight in the case of the Amazon.

The similarity analysis generates a statistic to identify the accuracy of the projected variable (in this case, deforestation) in relation to the observed value. The procedure consists on divide the areas into windows of equal size pixels and compare them in the projected scenario and observed scenario in order to detect how much the pixels identified as deforested area coincide in both scenarios. The similarity values between observed and simulated deforestation up to 2008 per biome are presented in Figure 32, Figure 33 and Figure 34.

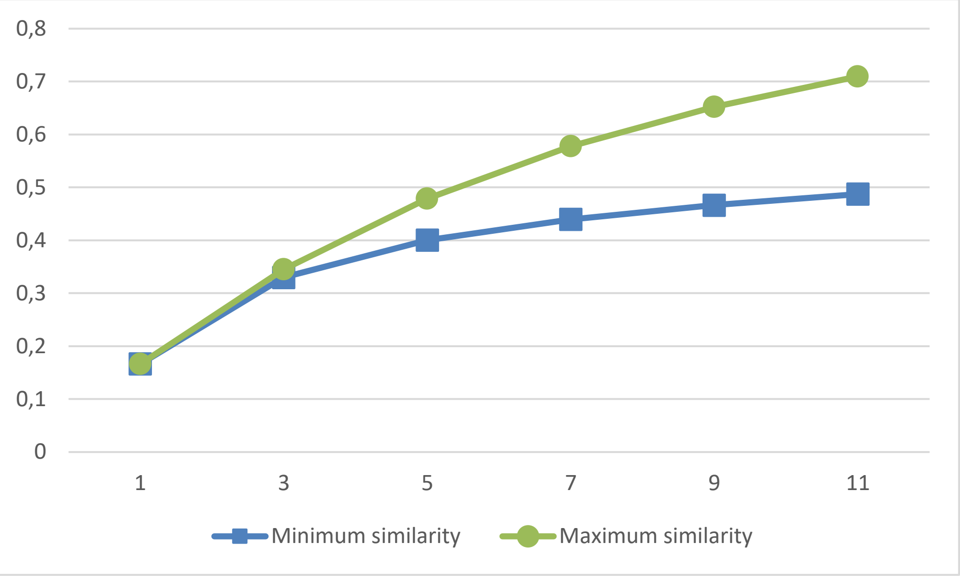


Figure 32: Maximum and minimum similarity between 2008 deforestation map and 2008 projected deforestation for Amazon biome.

Source: own elaboration based on Dinamica EGO results.

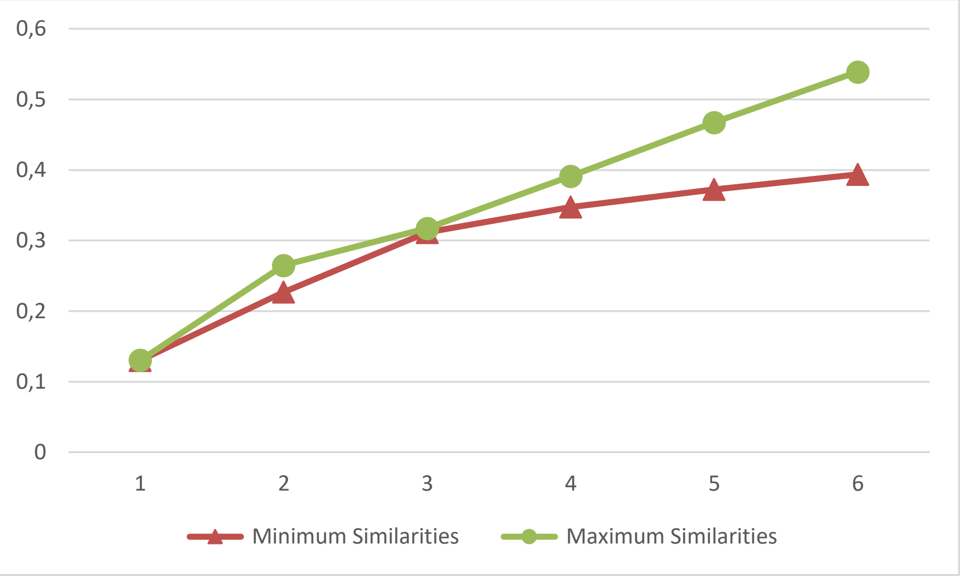


Figure 33: Maximum and minimum similarity between 2008 deforestation map and 2008 projected deforestation for Cerrado biome.

Source: own elaboration based on Dinamica EGO results.

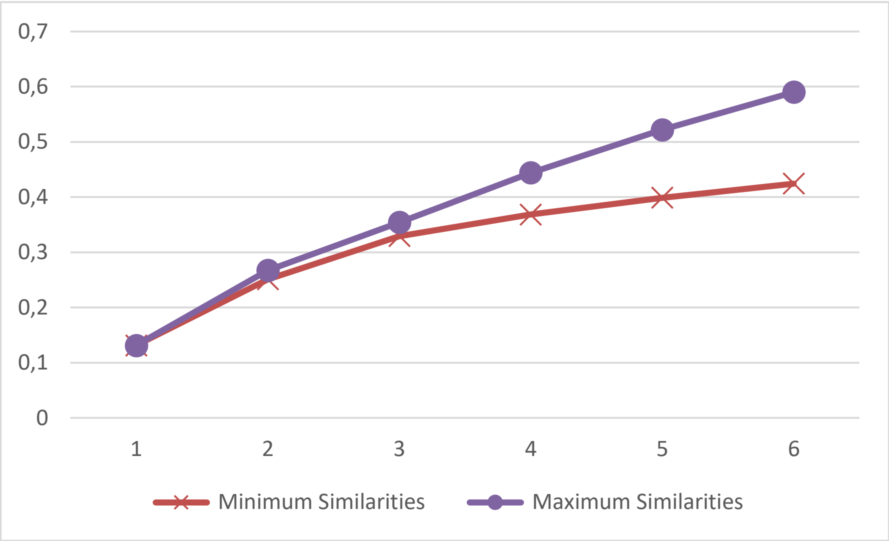


Figure 34: Maximum and minimum similarity between 2008 deforestation map and 2008 projected deforestation for Pantanal biome.

Source: own elaboration based on Dinamica EGO results.

For the Amazon biome (Figure 32), similarity had a maximum of 70% between the actual map and the projected map in 2008. In the Cerrado and Pantanal biomes, it was 60%. To understand better the concept of similarity, the example of the Amazon biome shows that if a 5-pixel window is analyzed, the maximum similarity is close to 50% (that is, half the projected changes correspond to the observed changes). If the analysis window is over 11 pixels, the maximum similarity increases to 70% (the simulated model captures 70% of changes in the observed model).

The next step was to extend the projection of deforestation by 2030, using the parameters estimated by the calibrated model for deforestation up to 2008. Figure 35 show the aggregate results of deforestation projections in each biome.

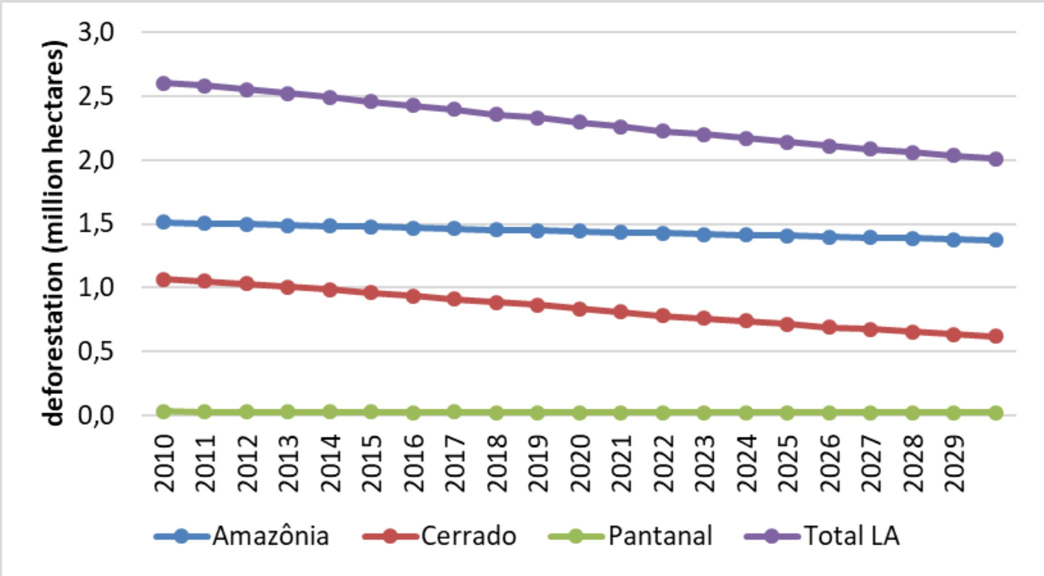


Figure 35: Deforestation projection for Brazilian biomes (2003- 2030) using Dinamica-EGO. Hectares.

Source: author elaboration based on results from Dinamica-EGO model.

Biome results show a decreasing deforestation trend (Figure 35). Cerrado biome is reducing deforestation rates faster than the Amazon biome. Pantanal biome is relatively stable with nearly 20.000 deforestation hectares per year. The effect on total Legal Amazon biome deforestation trend is clear: it has a trend (-1,28% annual growth) between the Amazon biome (-0,48%) and the Cerrado biome (-2,67%), a consequence of the interaction of both biomes.

Table 18: Observed deforestation and projected deforestation results by biome using Dinamica Ego.

Biome	Deforestation 2003-2015	Deforestation 2016-2030	Forest remnant 2002	Remnant 2015	Forest remnant 2030
Amazon	21.021.217	21.308.392	330.232.741	309.211.524	287.903.132
Cerrado	11.216.899	11.506.208	54.832.050	43.615.151	32.108.943
Pantanal	348.166	311.973	4.646.513	4.298.347	3.986.374
Total LA	**32.586.282**	**33.126.574**	**389.711.304**	**357.125.022**	**323.998.449**

Source: own elaboration based on Dinamica-EGO projection results

Table 18 show that, using Dinamica EGO methodology, Amazon biome continues to generate most of the deforestation in the Legal Amazon, with approximately 64% of total LA deforestation up t 2030. Cerrado continues with its trend with a 35%, with an accumulated total of 11,5 million hectares of deforestation up to 2030. Amazon presents the highest deforestation value, but when compared to forest remnant, participation of total deforestation between 2016 and 2030, compared to 2015 forest remnants, Cerrado presents a 21%, while Amazon and Pantanal represents a 7% total remnants share.

Table 19: Observed deforestation and projected deforestation by Federal Unit using Dinamica EGO

FU	Deforestation 2003-2015	Deforestation 2016-2030	Forest remnant 2002	Forest remnant 2015	Forest remnant 2030
AC	1.226.221	1.404.879	14.885.468	13.659.247	12.254.368
AM	1.720.946	1.972.750	144.136.563	142.415.617	140.442.867
AP	175.884	255.227	11.104.963	10.929.078	10.673.852
MA	3.679.829	3.608.961	16.644.130	12.964.300	9.355.340
MT	10.748.678	10.685.327	58.150.678	47.402.000	36.716.673
PA	7.435.305	7.186.098	94.452.308	87.017.003	79.830.906
RO	2.578.423	2.495.929	14.855.061	12.276.638	9.780.709
RR	836.176	1.123.992	15.303.448	14.467.272	13.343.280
TO	4.184.819	4.393.411	20.178.686	15.993.866	11.600.455
Total general	**32.586.282**	**33.126.574**	**389.711.304**	**357.125.022**	**323.998.449**

Source: own elaboration based on Dinamica-EGO projection results

If we analyze Dinamica EGO results by Federal Unit (Table 19) we find that highest deforestation will occur on in Mato Grosso, Pará and Tocantins. Maranhão shows the highest deforestation share to 2015 forest remnants: 28%. Mato Grosso and Tocantins have high deforestation share forest remnants: 23% and 27%. So, besides presenting high deforestation, total remnants reduction will be higher in this two FU.

Mato Grosso, Pará and Tocantins represent a very important agribusiness expansion area, in particular for pastures expansion, according to the analysis for figures 45 and 46, for the Ministry of Agriculture's agribusiness expansion plan.

4.1.6.4 Legal reserve deficit

Secondary vegetation in the recovery stage has a significant carbon capture capacity that should also be evaluated as a benefit by a possible National Environmental Services Payment Program. As a basic scenario to estimate the need for forest recovery, forest recovery needs were estimated from the requirements of the New Forest Code and the different regeneration rates of native forests in Brazil. From these values, and considering the estimates of carbon density in the native vegetation, one can estimate the carbon potential captured due to the recovery of native forests.

Four hypothetical scenarios were developed to deal with the environmental deficit, according to the level of recovery to comply with the New Forest Code: recovery of the Legal Reserve deficit (LRD) by 25%, 50%, 75% and 100%. Municipalities were organized from the biggest deficit areas to the smallest deficit areas. Results, expressed in tons accumulative hectares, are shown in the following table.

Table 20: Forest Code area compliance in the Legal Amazon by different compliance areas (hectares)

Biome	25%	50%	75%	100%	Total biome
Amazon	2.234.380	1.794.238	1.838.934	1.756.529	7.624.081
Cerrado	302.039	733.300	683.583	748.288	2.467.211
Pantanal			27.565	45.837	73.402
Total LA	2.536.419	2.527.538	2.550.082	2.550.654	10.164.694

Source: elaboration based on Soares-Filho et al. (2014)

Table 20 show that form the total 18.8 million hectares of deficit, Legal Amazon has a share of 53% (10,1 million hectares). From total LRD, Amazon biome has a share of 40,4% and Cerrado 12,7%. Largest areas correspond to the first quantile, while small areas correspond to the fourth quantile. Pantanal does not have municipalities with large areas (in 25% or 50% quintiles), while Cerrado has an even distribution among quintiles 2, 3 and 4. Amazon biome presents an interesting future: it has 437 municipalities with small areas (up to 19.571 hectares) to comply with the FC. Cerrado has 180 municipalities in the same category. For large LRD areas, Amazon accounts for 18 municipalities while Cerrado accounts only with 3 municipalities.

Based on this information it is possible now to establish the impact of a PES scheme to have different compliance levels, and crosscheck it with the information on opportunity costs.

4.1.7 Discussion

Agribusiness projections and deforestation

Vieira Filho (2016) showed that in cattle ranching sector, increase of cattle performance correlates with genetic improvement, balanced nutrition, pastures quality and management innovation. Meanwhile, pastures growth is a reflection of opportunity costs, like beef prices, completion with food production and terms of exchange for modern inputs. In addition, Vieira Filho (2016) states that pastures growth is correlated with opportunity costs like meet price, competition with food production and exchange terms for modern inputs.

Cattle ranching dependence on deforestation

The evolution of cattle herd, pastures and stocking rates for the Brazilian Legal Amazon as whole, and by states showed that there will be an increase in deforestation in order to reach the policy goals for agribusiness up to 2030. This seems not to be good news for forest areas for the next 15 years. At least for the Legal Amazon, the increase in the agricultural area is done at the expense of forest areas. This strategy is very different from the one analyzed by Jank et. al (2014) between 2006 and 2012, and Reis (2016) between 1975-2005, where national grazing ratios played an important role offsetting the loss of grasslands to agricultural lands (specialization).

Jank et al. (2014) suggest that beef production increased in Brazil, based on pastures reduction and increase of grains and sugar cane areas (between 1995 and 2006), an 84% deforestation reduction (between 2004 and 2012), and an increase of 22% of cattle heads (between 2001 and 2011). Reis (2016) made a similar analysis between 1975 and 2005 and concluded that patterns of growth were characterized by a small expansion of cattle ranching with a significant intensification of pastures (grazing ratio) and a small reduction of cattle specialization. However, most of the action was concentrated in the 90's where both, area under farm and herds contracted, while pasture showed a significant increase in productivity and cattle specialization a significant reduction (see Figure 36)

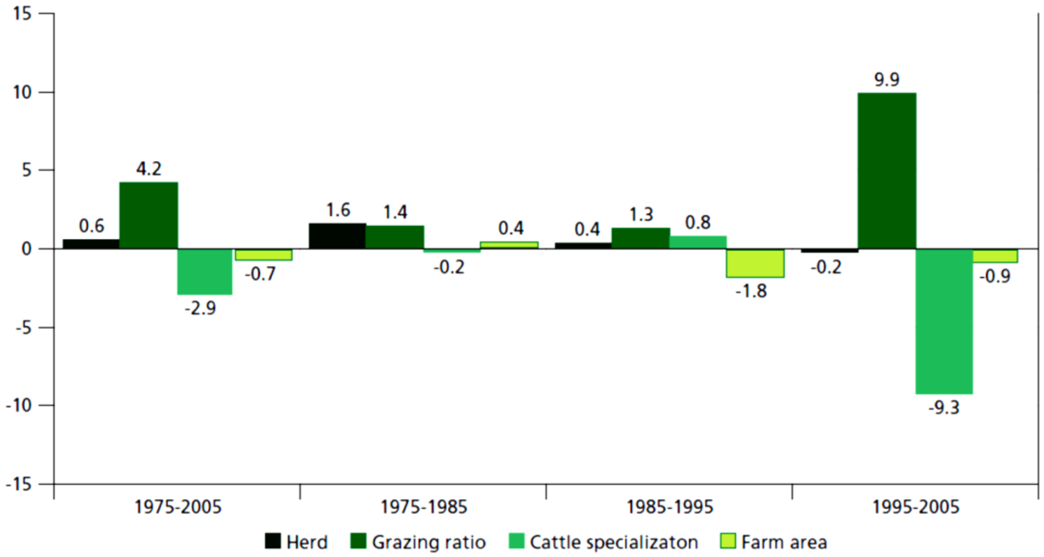


Figure 36: Average growth rates of municipal herd, grazing ratio, cattle specialization, and farm area for inter-census periods – Brazil (1975-2005) (In % p.a.)

Source: Reis (2016)

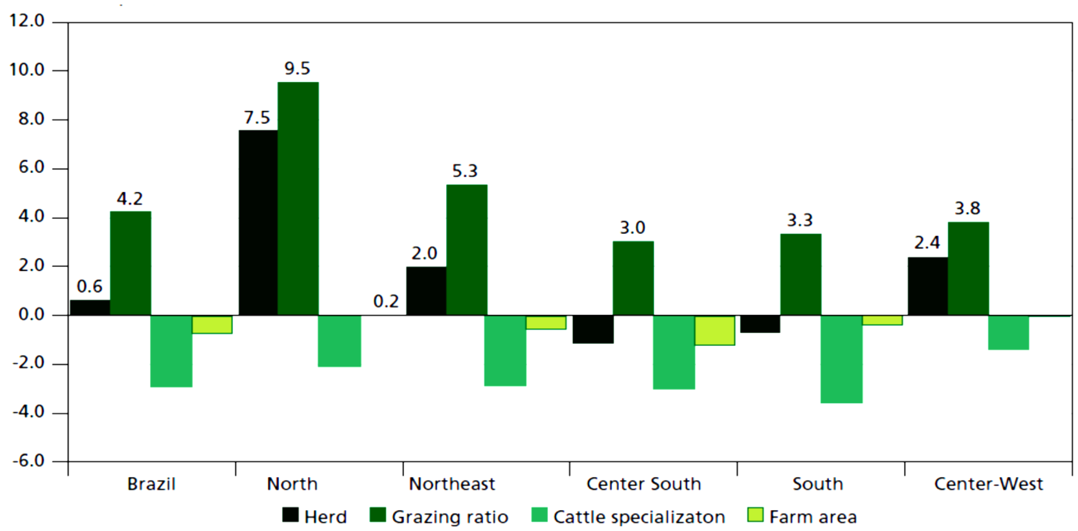


Figure 37: Average growth rates of municipal heard, grazing ratio, cattle specialization and farm area by regions (Brazil 1975-2005)

Source: Reis (2016)

Figure 37 show that cattle herd in Northern states presented highest growth average. This can be explained mainly because of grazing ratio increase for the 1975-2005 period.

Future monitoring of these expected trends should be taken into account in policy formulation, in particular for credits granting and monitoring and evaluation.

Previous analysis of cattle growth rates, derived from government's projections of agribussines, show that the future of cattle ranching in LA will be of intensification, trying to increase stocking rates, but still with a dependence on pastures expansion due to the countries expectations of future beef demand. It is worth mentioning that our cattle and pastures projections include a small increase on the stoking rate (Table 14) between 2016 and 2026, showing an 17% increase for LA states, 10% increase for non-LA states and 13% increase for Brazil. The issue here is which are the government plans that allow this increase in stocking rate? Is it generated through technical assistance or through soft loans for new technologies acquisition? How are the governmental or non-governmental agencies responsible of developing such a cattle ranching intensification strategy? Some partial answers can be found in the chapter on policies' analysis.

DEFORESTATION COMPARISON BETWEEN SISGEMA AND DINAMICA EGO

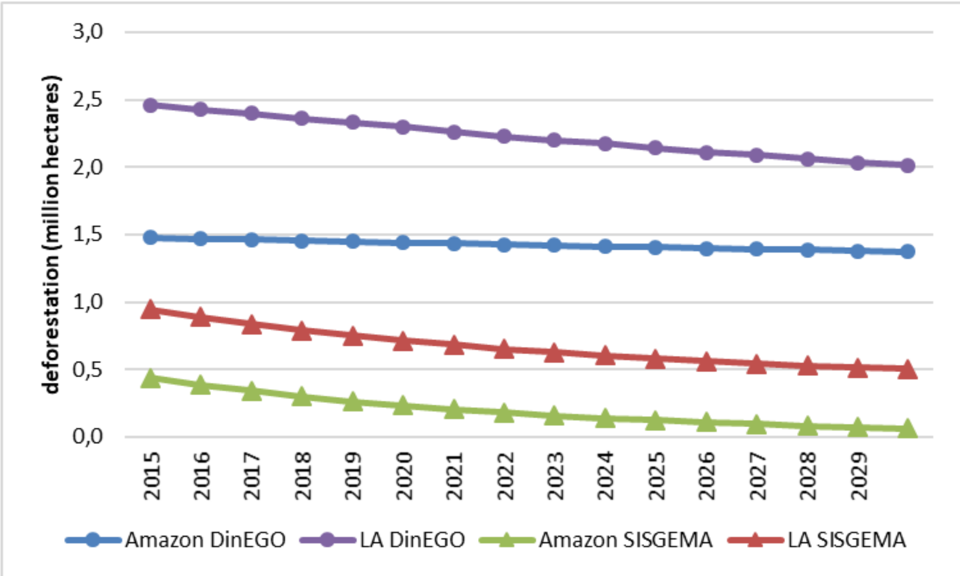


Figure 38: Comparison between deforestation projections for Brazil and Legal Amazon using SISGEMA and Dinamica-Ego (2015-2013).

Source: own elaboration based on Dinamica EGO projection results

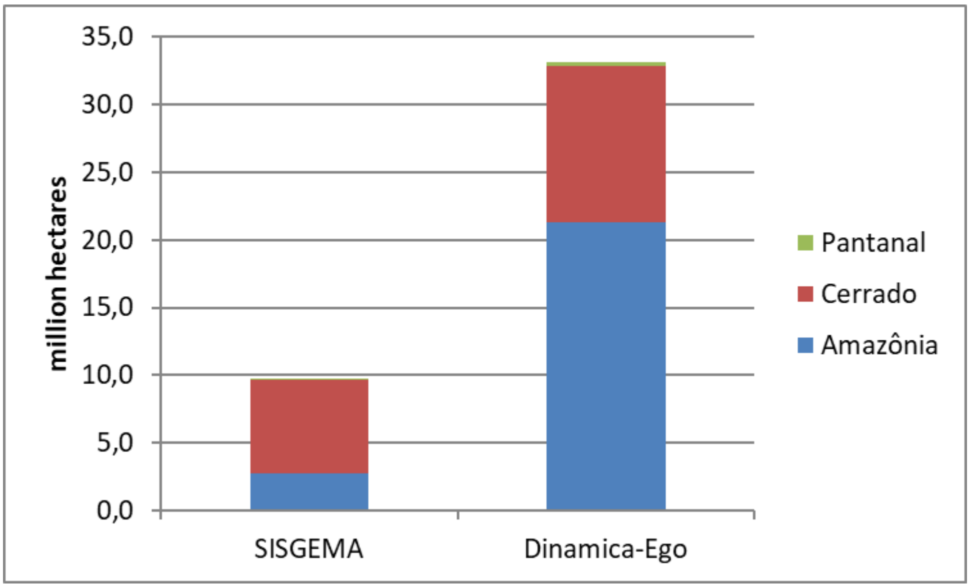


Figure 39: Accumulated deforestation for Legal Amazon by biome, using SISGEMA and Dinamica-EGO (2015-2030)

Source: own elaboration based on Dinamica EGO and SISGEMA projection results

It is important to note that the projections are decreasing for the different biomes when comparing SISGEMA and Dinamica EGO. When comparing both models, projections are decreasing, but the amount of deforestation projected by biome has higher values in the Dynamic-Ego projection. Figure 54 and 55 contrasts the deforestation projections in the two scenarios. It can be seen that by the Ego Dynamics, deforestation in the Amazon would be higher than in the Cerrado, but in the scenario of the Exponential SISGEMA model, the projection of deforestation in the Cerrado would be much higher. These figures are related to deforestation rates calculated annually and for the whole period 2002-2008. Therefore, in the face of more recent changes in deforestation trends, it is possible that deforestation rates will decrease compared to those calculated in this study.

It is important to stress that the Dinamica EGO platform is strongly dependent on the base period for the analysis - in this case, the years 2002 and 2008. However, there was a great structural variation in the deforestation behavior after this period, with a significant reduction in deforestation in Amazonia and expansion in the Cerrado, the projections based on the Dinamica EGO platform differ greatly from those obtained by the SISGEMA model: as a whole, the deforestation projected based on the Dinamica EGO platform is much larger than that projected by SISGEMA, and the observed in recent years. Spatially, the main difference is the projection of a much larger deforestation in the Amazon (21.3 million hectares with Dinamica EGO and 2,7 million hectares using SISGEMA) and much smaller in the Cerrado (11,5 million hectares using Dinamica EGO and 6,8 million hectares using SISGEMA). Again there is a discrepancy with the data observed for the recent period. For this reason, it is recommended that the results obtained by the SISGEMA Model be adopted as the best approximation, and that the results obtained using the Dinamica EGO platform should be perceived as a maximum limit, possibly projecting the deforestation that would have occurred if the measures of governance adopted since the mid-2000s had not been implemented.

Deforestation projections using the Dinamica EGO model were higher than those obtained in SISGEMA model. The largest differences are in the Amazon biome, while for Cerrado the projections have closer values between the two methodologies. This indicates that there are advantages and disadvantages in the use of the Dinamica EGO model. It allows generating a spatial location of projected deforestation, identifying priority areas where deforestation is most likely to occur. However, the Dinamica EGO model can overestimate deforestation values when compared to other methodologies, such as the SISGEMA model, used in the first part of deforestation estimates. This is because changes in historical trends may not be properly captured in the processes of identifying deforestation rates. Therefore, it is necessary to obtain information from more recent years, reflecting better the short-term trends.

The accuracy of deforestation areas location will also depend on the quality of information being used as input to determine the weights of evidence of the different spatial variables. Again, it is fundamental to have up-to-date information on these spatial variables to minimize errors in projections.

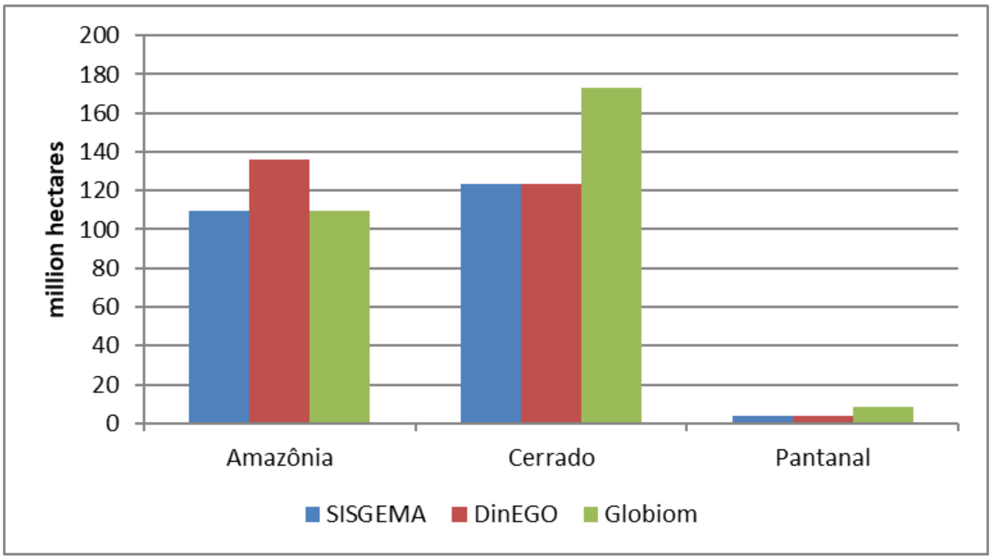


Figure 40: Comparison between Dinamica Ego, SISGEMA and Globiom results for total deforestation up to 2030.

Source: Camara et al. (2015) and SISGEMA-DiamicaEGO projections

Globiom (GLObal BIOsphereManagement model) is a model of bottom-up partial equilibrium analysis that focuses on land-use sectors such as agriculture, forestry, and biofuels (Câmara et al. 2015). This model generates estimates for different Brazilian biomes. Therefore, to generate a comparison between GLOBIOM, SISGEMA and Dinamica EGO we will make a Legal Amazon's biomes comparison. GLOBIOM model calculated an accumulated deforestation of 291 million hectares by 2030 for Amazonia, Cerrado and Pantanal (11% more than the projection using the Dinamica EGO model). GLOBIOM projected deforestation in the Cerrado biome of 173 million hectares, 41% more than the Dinamica EGO model. In turn, Amazonia was the second biome, with 109 million hectares accumulated deforested until 2030, 20% less than the projection of the Dinamica EGO model.

According to SISGEMA, total accumulated deforestation in these three biomes, by 2030 would be about 236 million hectares, while GLOBIOM projects approximately 291 million hectares (23% difference). In the year 2030, the projection of total stocks of forest remnants in the SISGEMA scenario and of mature forests in the GLOBIOM Model are very similar for Amazon, around 313 and 315 million hectares in the usual business scenario. That is. SISGEMA has a much greater affinity with GLOBIOM than with Dinamica EGO for the Amazon

The main differences between the SISGEMA scenario and the GLOBIOM model occur at the biome level. For the Amazon, GLOBIOM projects less deforestation and larger forest remnants, however in the Cerrado the deforestation projections are larger and forest remnants smaller than those projected by the SISGEMA model scenario. This indicates that data updating efforts and methodological improvement must persist to ensure better future deforestation projections, as a subsidy for the implementation of PSA for forest conservation.

These results also show that SISGEMA model has the advantage of having greater adherence to the recent evolution trends of deforestation. For this reason, it is advised to use the future deforestation projections obtained by SISGEMA.

4.2 Understanding biophysical impacts.

4.2.1 BAU vs SEM scenarios for deforestation

This component refers to the estimation of greenhouse gas (GHG) emissions, notably carbon dioxide (CO_2), which would no longer be released into the atmosphere due to the establishment of a national PES - in the literature, this component is known as Reductions of Emissions from Avoided Deforestation and Forest Degradation (REDD).

The first step in estimating the benefits of REDD induced by a national PES is to survey local forest remnants at the municipal level. For this purpose, the database of the "Brazilian Biome Deforestation Monitoring Project - PMDBBS" (IBAMA, 2011) is used, which defines forest remnants and/or average deforestation rates for all municipalities in Brazil separated by biomes. Information from the Amazonian biome, in particular, comes from the PRODES system, organized by the National Institute for Space Research (INPE, 2014).

Second, we used opportunity cost from Young (2016). These data are based on 2013 values, so, we used the implicit GDP deflator to translate information to 2016 BRL. In addition, we used the 2016 exchange rate, to translate information to US dollars. We proposed as a PES value

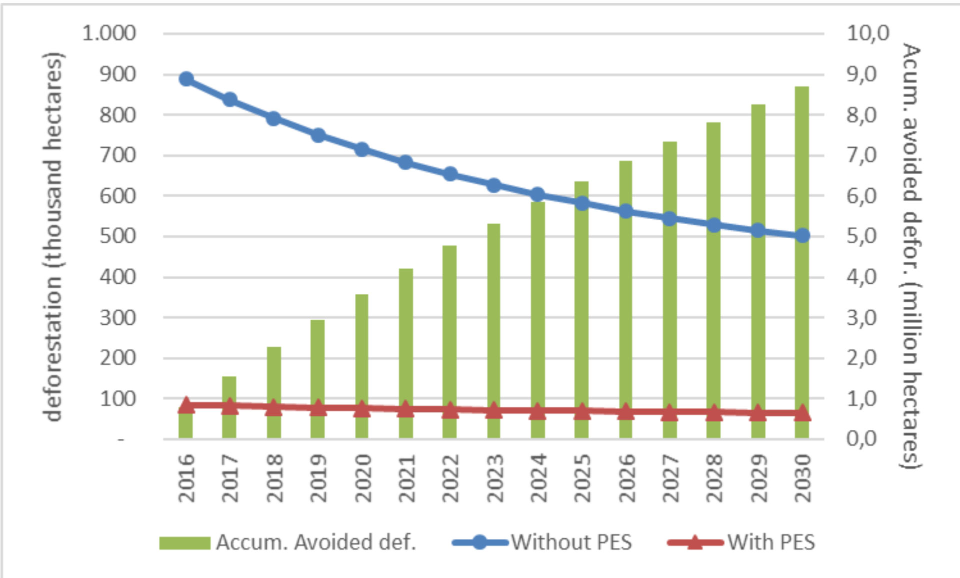


Figure 41: Deforestation projection using SISGEMA with and without PES. 2016-2030. Million hectares.

Source: own elaboration based on SISGEMA projections data.

This scenario contrasts with Federal Government's goal to eliminate deforestation in all Brazilian biomes until 2030, despite the even shorter term for the Amazon biome. The difference between the projected trajectory for deforestation rates and that, which would be required to meet the commitments, shows the insufficiency of the current instruments in operation, which shows the possibility of filling these gaps through a national policy of payments for environmental services with a specific focus on forest conservation.

As an alternative to the business as usual scenario, a PES was assumed to pay the maximum equivalent to the median opportunity cost of land for all Brazilian municipalities (USD $143,04/ha/year[24]), that is, to focus policy efforts in the two quartiles where conservation would be cheaper for the whole country. The results showed that by paying this amount, it would be possible to reduce total deforestation in the period by approximately 8,6 million hectares, which is equivalent to 88, 8% of the projected deforestation (see figure 57) for the whole period.

An additional point of view is to use the median value of the opportunity cost for the Legal Amazon municipalities, which amounts USD$ 69,24/ha/year. Using a PES scheme based on these value, avoided deforestation will be 5,1 million hectares.

4.2.2 Changes in attributes (BAU vs SEM), CO_2 emissions

Different policies can be proposed to address deforestation in the Legal Amazon. Different values of a PES scheme payment, in a per hectare basis, can generate different values of avoided deforestation, and determine different cost-effective areas. The associated value of the avoided emissions of CO_2 also have an important variation, depending on the quantity of carbon stocked in different types of forests

Dos Santos (2010) calculated amount of carbon stock by type of forest for Brazil. We used that information to calculate a mean value for each municipality, and in particular for LA municipalities. The results are shown in Map 17.

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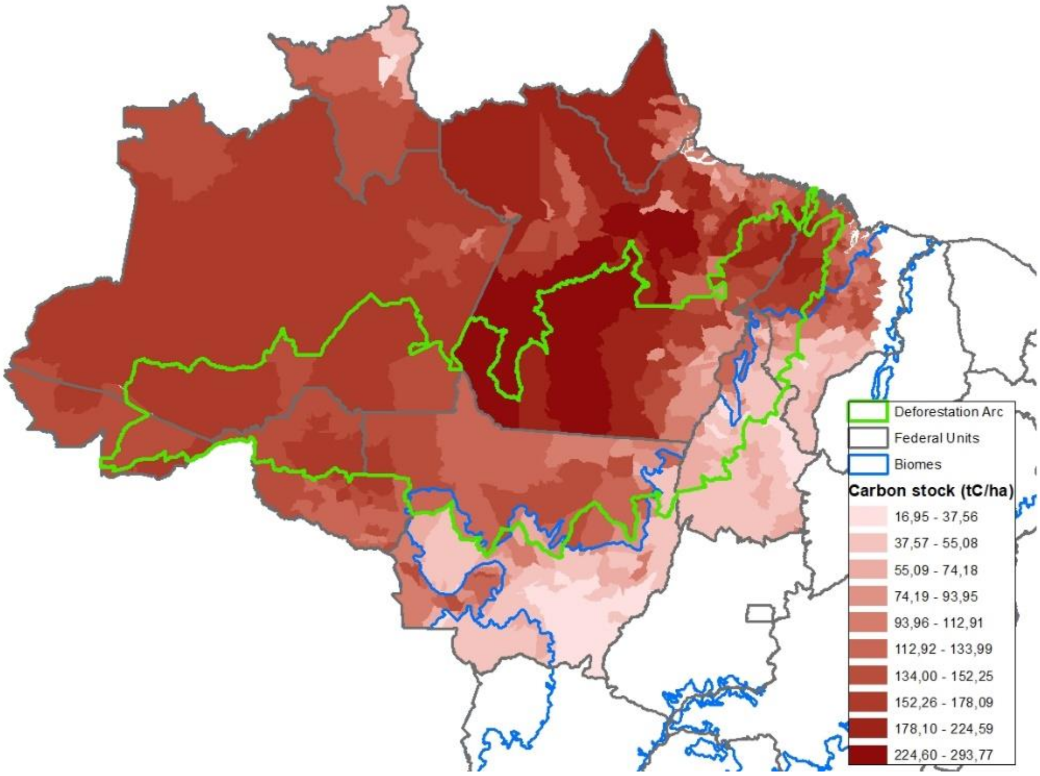
[24]Original median value was BRL $402,57, and it was updated using the implicit deflator for GDP between 2013 and 2016 (1,24) and an exchange rate of 3,49 BRL/USD.



Map 17: Carbon stock calculated for each municipality of LA (tC/ha)

Source: own calculations based on Dos Santos (2010)

Map 17 shows that there are important differences between forest carbon stocks by biomes. Amazon forests show higher carbon stocks than Cerrado and Pantanal: mean value for Amazon municipalities was 137,79 tC/ha, for Cerrado was 73,9 tC/ha and for Pantantal was 47,1 tC/ha. When establishing a PES scheme, carbon stock must be taken into account to compensate different carbon stocks associated to different type of forests. Forests with highest carbon stocks are located within southern Para municipalities, followed by Para's eastern municipalities and Amapas' and Amazon's municipalities. There is an important forest stock where high deforestation rates are being reported, associated to the deforestation arc.

We used this information and transformed the carbon stocks, into carbon dioxide equivalent units (CO2eq)[25]. We combined this information with the amount of avoided deforestation by municipality and estimated curve of avoided emissions.

[25] To transform one ton of carbon (C) into carbon equivalent (CO_2eq) units we must multiply by 44/12, which is the amount of carbon contained in a carbon dioxide molecule.

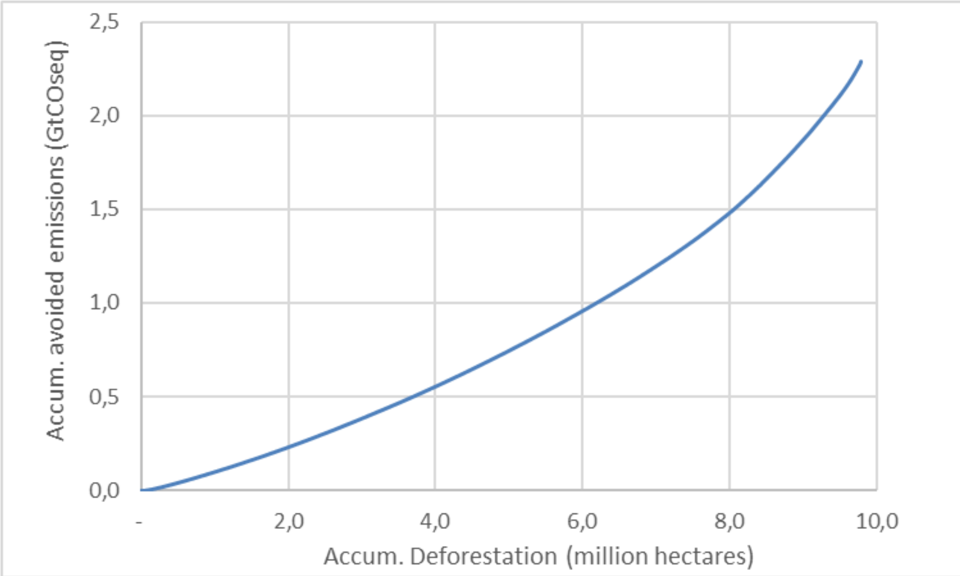


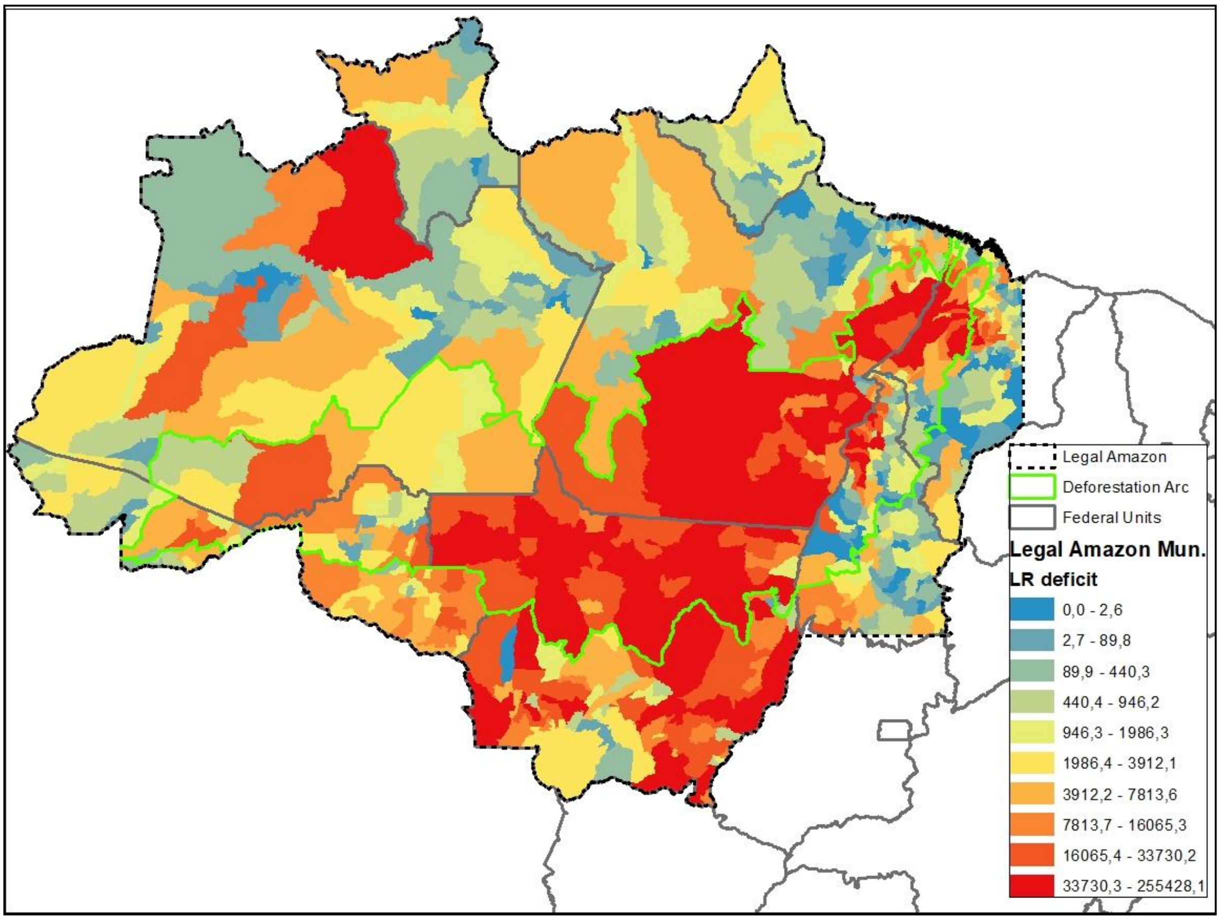
Figure 42: Avoided CO_2 emissions up to 2030 by PES in SISGEMA model

Source: own elaboration based on SISEMA model results.

Figure 42 shows the quantity of avoided emissions that are associated to a policy reaching different levels of avoided deforestation areas. For an area of 8,6 million hectares, that is associated with the PES of USD $143,04/ha/year, the associated avoided carbon emissions will be 1,7 $GtCO_2eq$. For the alternative scenario, paying the median value for the LA municipalities (USD$ 69,24/ha/year), the associated avoided carbon emissions will amount 0,77 $GtCO_2eq$.

4.2.3 Changes in attributes (BAU vs SEM), reforestation for LR compliance

Legal Reserve deficit varies according to the biome in which the municipality is located. For municipalities in the Amazon, properties located in forested areas must conserve 80% of its forest areas. In Cerrado, Legal Reserve has a value or 35% of forest area present in a property, and for Pantanal it goes up to 20%. There is a not homogenous compliance of Legal Amazon percentages along different biomes, and as we saw later, deforestation and forest remnants vary along time. Based on Soares-Filho et. al (2014), we identified the quantity of forest deficit following the last Forest Code modifications. The following maps shows forest deficit to comply with new Forest Code decisions.



Map 18: Legal Reserve deficit in Legal Amazon.

Source: own elaboration based on Soares-Filho et al. (2014).

LR deficit, organized by area's size, is located mainly in municipalities from Mato Grosso, in particular, northern and eastern municipalities (Map 18). In addition, for Pará municipalities, highest deficit area are located in the southern and eastern. Some other important municipalities with area's deficit are located in northern Tocantins, northern Maranhão, northern and southern Amazon and southeastern Acre. Mean value per municipality is 11.344 hectares. Top five municipalities are located in Mato Grosso: Gaúcha do Norte (151.313 ha), Juara (185.167 ha), Marcelândia (135.829), Querência (235.578 ha) and São José do Xingu (255.428). All this five municipalities account for nearly 825.500 hectares, with a share of 8% of total LA deficit.

We used equation 7 (carbon capture from reforestation and deficit area), to estimate total emissions by municipality. Figure 43 shows total carbon capture by reforestation in each municipality in the Legal Amazon, and accumulated reforestation area to comply with LR.

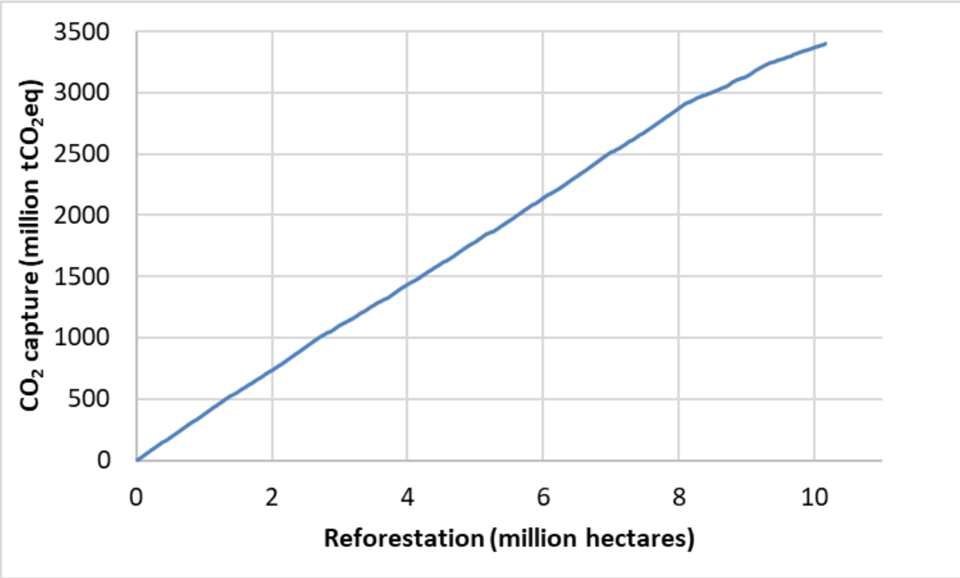


Figure 43: Total carbon capture and reforested area to comply with Legal Reserve from new Forest Code decisions.

Source: own elaboration based on SISGEMA model results

Figure 43 shows that if there is a complete compliance of Legal Reserve percentages for municipalities within the Legal Amazon (10,1 million hectares' deficit), total carbon capture by reforestation can reach 3500 million tCO_2eq. Additional scenarios can assume 25%, 50% and 75% compliance. For these scenarios total amount of reforestation and CO_2 capture are: 2,5 million hectares and 881 million tCO_2eq; 5 million hectares and 1.786 million tCO_2eq; 7,6 million hectares and 2.721 million tCO_2eq.

The alternatives for a SEM scenario can be evaluated only when taking into account associated fencing costs and opportunity cost.

4.3 Valuing impacts through economic modelling and PES

4.3.1 PES scheme for avoided deforestation

It is possible to estimate the annual value of the policy and its extent as a function of the opportunity cost of the land in the areas that would be deforested between 2016 and 2030 (Figure 59). We estimate the annual accumulated deforestation curve (supply curve) for the Legal Amazon and compare it with the one for the whole country.

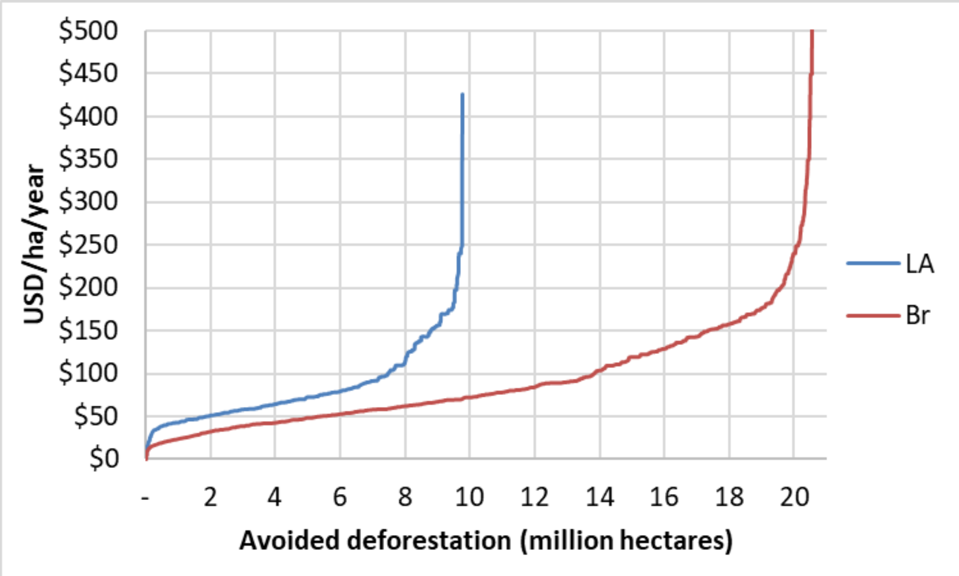


Figure 44: Forest conservation supply curve for Legal Amazon and Brazil

Source: own elaboration SISGEMA model results.

It is noted that with a PES cost of up to USD $143,04/ha/year, it is possible to get 8,6 million hectares of avoided deforestation, approximately 88% reduction (Figure 44) . This curve lies above the one for Brazil, because cheaper areas can be found outside the LA, and therefore, can be covered by the proposed incentive amount, and reaching a larger amount of area for the same proposed cost. If we use the same criteria for the whole country, the amount of area would be nearly 17 million hectares.

In the alternative scenario, where we use the median value for the LA (USD 69,24/ha/year), it is possible to avoid deforestation of 4,7 million hectares.

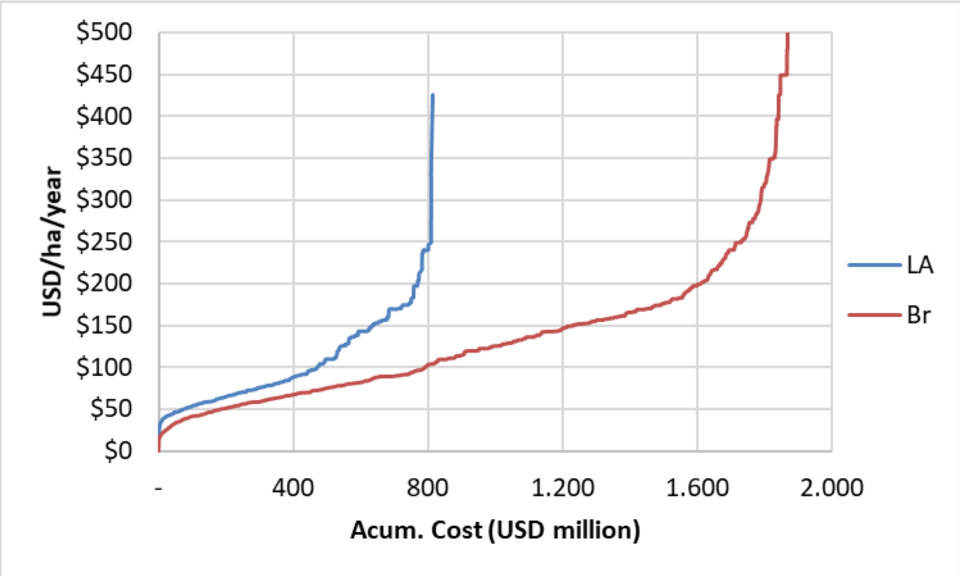


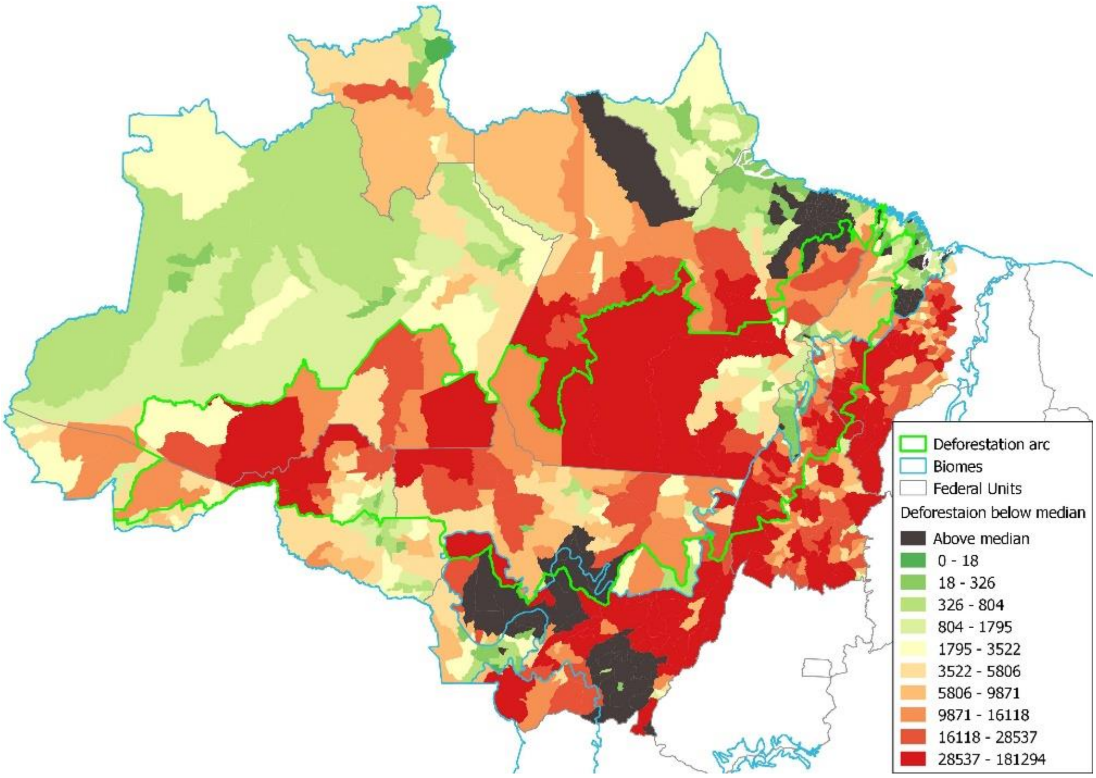
Figure 45: Forest conservation accumulated costs and opportunity cost.

Source: own elaboration SISGEMA model results

Figure 45 consists of the payment of the areas for which losses of forest remnants were projected, and reveals the cost of avoiding deforestation that could occur at any point in time, from this moment until 2030. It shows that at the proposed median opportunity cost rate (for Brazil), for the PES scheme, associated cost in the Legal Amazon would be USD$ 592 million per year, in comparison with a total cost of USD$ 1.183 million for the whole country. What this figures shows us is that some of the cheapest areas can be found in the LA, but there are still some cheap areas in municipalities outside the Legal Amazon.

For the alternative scenario where the median value for LA is used there is a total USD $339 million associated cost, by the proposed policy implementation.

The following maps show the two alternative policies: using median value of opportunity cost for Brazil and for Legal Amazon.



Map 19: Spatial distribution of avoided deforestations (below BR median) and residual (above median) for 2016-2030.

Source: own elaboration

The effectiveness of a PSA paying the maximum value of USD $143,04/ha/year is quite uneven in spatial terms. This is due to regional differences in the opportunity costs of land. In Map 19 we can see the successful region for policy implementation. Fundamentally, if drawn in these terms, the PSA would be very effective in reducing deforestation in the Pampa and Amazon biomes. Some municipalities (black regions) will not be included in this policy in Cerrado biome. Municipalities covered by this policy amount 666 out of 771 municipalities. 24 municipalities do not have deforestation projection and 81 municipalities lie above the median value.

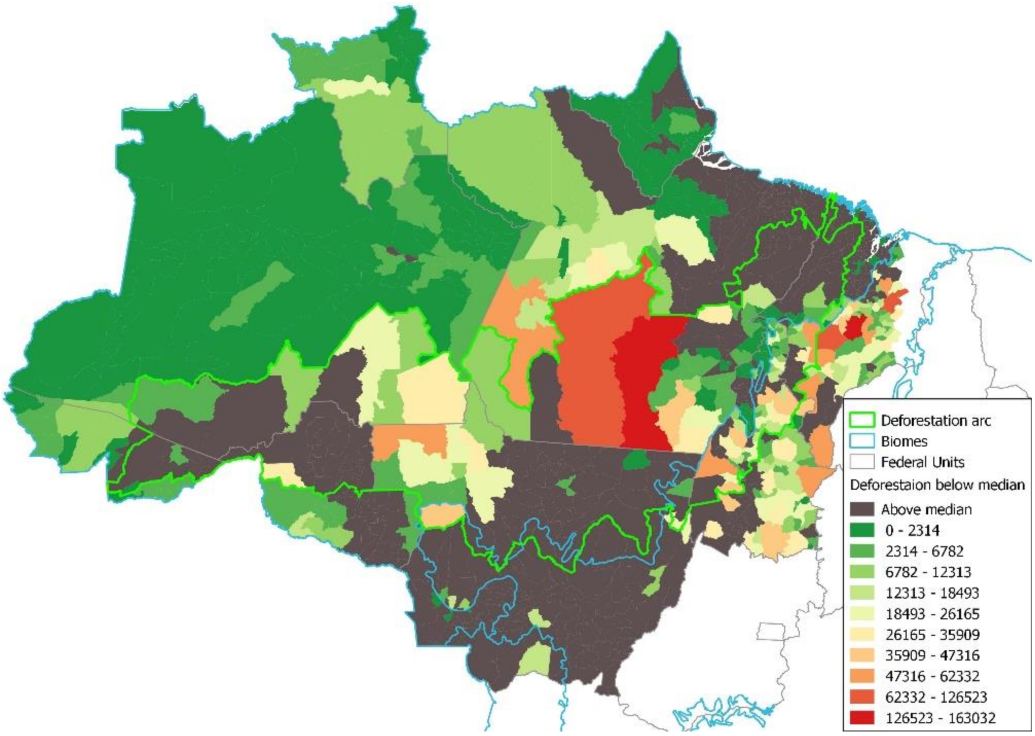
Table 21: Avoided deforestation using two different OC median values

Biome	Def above median LA	Def. below median LA	Def below median BR	Def. above median BR	Total deforestation
Amazon	1.439.693	1.319.664	2.651.559	107.798	2.759.357
Cerrado	3.199.457	3.705.194	5.921.879	982.772	6.904.651
Pantanal	18.553	104.504	118.998	4.059	123.057
Total LA	4.657.703	5.129.362	8.692.436	1.094.629	9.787.065

Source: own elaboration

This policy will reduce projected deforestation up to 96% for Amazon, 54% for Cerrado, 96% for Pantanal and 89% for whole LA (Table 21). This policy is very effective for Amazon and Pantanal biomes, but still some deforestation will be left. For Cerrado, we can see that some high opportunity cost municipalities lie above this median value.

If we consider the alternative policy of paying the median value for LA municipalities, total avoided deforestation will be 5.1 million hectares. Percentage of avoided deforestation by biome will be 48% for Amazon biome, 38% for Cerrado, 85% for Pantanal and 52% for LA. Distribution of avoided deforestation by municipality can be seen in Map 20.



Map 20: Spatial distribution of avoided deforestations (below LA median) and residual (above median) for 2016-2030.

Source: own elaboration

Map 20 shows that PES payment using the median for the LA municipalities reduces the scope of policy: only northeastern Mato Grosso municipalities will be included, and some municipalities from Rondônia and Acre will not be covered. In addition, some municipalities in northern Maranhão and northeast Pará will be excluded.

Table 22: Avoided deforestation by biome applying median OC for Brazil, by biome

Biome	Amazon	Cerrado	Pantanal	Total LA
Projected deforestation (ha)	2.759.357	6.904.651	123.057	9.787.065
Avoided deforestation (ha)	2.651.559	5.921.879	118.998	8.692.436
Abatement %	96%	86%	97%	89%
Total emissions (tCO_2equ)	1.676.293.116	1.710.860.339	22.344.529	3.409.497.984
Suma de CO_2eq total	1.611.543.890	1.518.373.281	21.773.012	3.151.690.183
Total cost of PES (USD/year)	$177.687.677	$430.155.467	$10.091.776	$617.934.919
Total cost USD (15 years)	$1.829.291.775	$4.428.443.621	$103.894.668	$6.361.630.064

Source: own elaboration

Table 23: Avoided deforestation by Federal Unit, applying median OC for Brazil

FU	BAU	SEM, below median OC for BR			
	Projected def. (ha)	Avoided def. (ha)	Abatement (%)	Cost USD (year)	Cost USD (15 years)
Mato Grosso	3.394.376	2.378.870	70%	$225,8	$2.325,1
Maranhão	2.201.550	2.200.664	100%	$131,1	$1.349,6
Tocantins	2.051.333	2.051.333	100%	$129,5	$1.333,4
Para	1.370.686	1.292.448	94%	$80,4	$827,5
Rondônia	342.744	342.744	100%	$30,0	$309,2
Amazonas	210.833	210.833	100%	$10,3	$106,3
Acre	106.457	106.457	100%	$6,7	$69,1
Roraima	88.724	88.724	100%	$2,8	$28,5
Amapá	20.362	20.362	100%	$1,3	$13,0
Total LA	9.787.065	8.692.436	89%	$617,9	$6.361,6

Source: own elaboration

In Table 22 and Table 23 Amazon and Pantanal biomes are close to end deforestation, using a median value of opportunity cost for Brazil. Cerrado continues with high deforestation areas, (approximately 14% of total projected deforestation). In this scenario, the only two states that do not end deforestation are Mato Grosso and Pará.

A policy like this can avoid 92% of total associated emissions, and it has a total associated cos of USD $617 million on a yearly basis or a total of USD $6.3 billion, if PES covers opportunity cost for 15 years. Most of budget will be used on Cerrado, on a biome basis, and on Mato Grosso, Maranhão and Tocantins, on a Federal Units basis. It is interesting to notice that, even though Mato Grosso will have the highest expenditure on PES payment, it still presents high deforestation rates: there is still a 30% projected deforestation remaining.

Federal Units with lowest expenditure on PES and lowest projected avoided deforestation are; Amapá, Roraima, Acre and Amazonas. Despite this fact, these states will end deforestation.

Table 24Avoided deforestation by biome applying median OC for Legal Amazon

Biome	Amazon	Cerrado	Pantanal	Total LA
Projected deforestation (ha)	2.759.357	6.904.651	123.057	9.787.065
Avoided deforestation (ha)	1.439.693	3.199.457	18.553	4.657.703
Abatement %	52%	46%	15%	48%
Total emissions (tCO_2equ)	1.676.293.116	1.710.860.339	22.344.529	3.409.497.984
Avoided emissions (tCO_2eq)	928.633.936	918.289.037	3.638.710	1.850.561.683
Total PES cost (USD/year)	$66.696.902	$173.232.933	$1.140.021	$241.069.856
Total PES cost (15 years)	$686.643.538	$1.783.430.258	$11.736.493	$2.481.810.289

Source: own elaboration

Table 25: Avoided deforestation by Federal Unit, applying median OC for Legal Amazon

FU	BAU	SEM, below median OC for LA			
	Projected def. (ha.)	Avoided def. (ha)	Abatement (%)	Cost USD (year)	Cost USD (15 years)
Mato Grosso	3.394.376	347.289	10%	$17,9	$183,9
Maranhão	2.201.550	1.612.758	73%	$85,4	$878,8
Tocantins	2.051.333	1.484.755	72%	$83,1	$855,9
Para	1.370.686	817.222	60%	$38,3	$394,3
Rondônia	342.744	80.056	23%	$4,3	$43,8
Amazonas	210.833	150.939	72%	$5,5	$56,6
Acre	106.457	61.202	57%	$3,2	$32,6
Roraima	88.724	88.724	100%	$2,8	$28,5
Amapá	20.362	14.758	72%	$0,7	$7,4
Total LA	9.787.065	4.657.703	48%	$241,1	$2.481,8

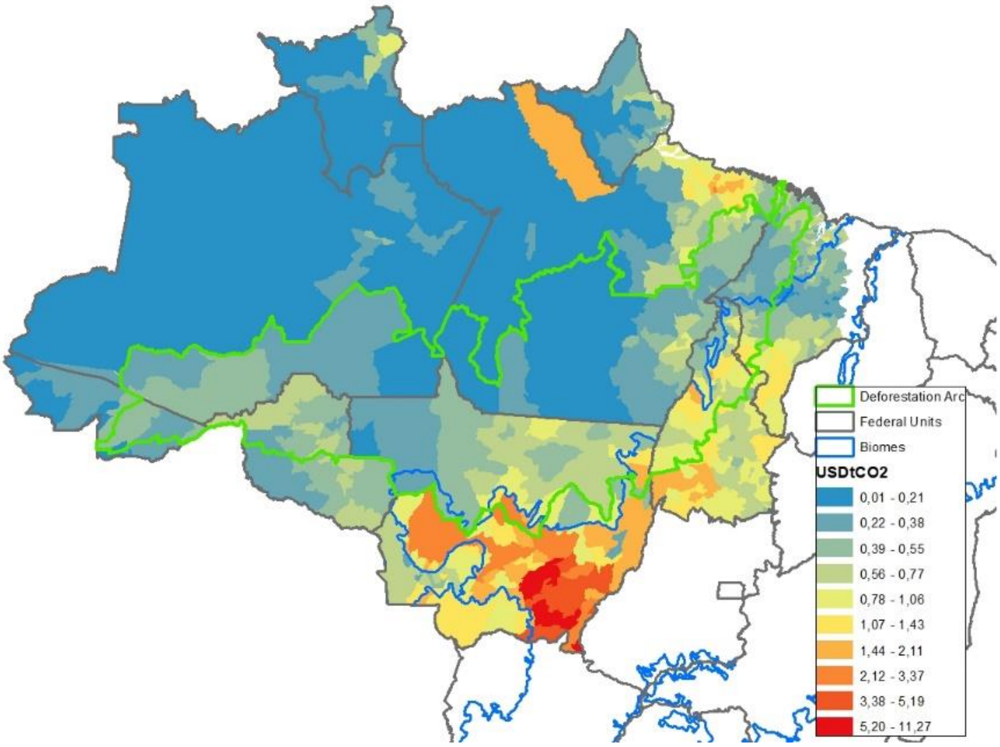
Source: own elaboration

Table 24 and Table 25 show that, if using median opportunity cost for Legal Amazon municipalities, then Pantanal only reduces 15% of its projected deforestation while Cerrado presented a 46% deforestation reduction. Nearly half of total deforestation is avoided in Amazon biome. In this scenario, the only one state reduces completely its deforestation: Roraima, and Mato Grosso, Rondônia and Acre have the lowest deforestation abatement

A PES for avoiding deforestation, using the median value of opportunity costs of Legal Amazon states, will be able to reduce deforestation on 48%, with an associated cost of USD $241 million on a yearly basis payment or USD $2,4 billion, if payment cover 15 years of production activities. Expenditure on PES policy will be reduced on Mato Grosso and in Pará. High deforestation reduction will still be present on Maranhao, Tocantins, Amazonas and Amapá, because of deforestation projected on low opportunity cost lands.

4.3.2 PES scheme for CO_2 emissions reduction

In previous section, we determined the quantity of avoided deforestation that can be reached when there is an amount of PES defined per hectare per year. Another way in which the proposed policy can be analyzed is related with the associated carbon dioxide emissions associated to avoided deforestation. One of the first steps is to determine the price for each ton of carbon that will be paid for each area associated with avoided deforestation. In previous sections we saw that forest carbon stock is unevenly distributed throughout the Legal Amazon. In addition, opportunity cost of land is also unevenly distributed. As a consequence, the implicit price of carbon emissions reduction, associated to avoided deforestation, will be influenced by these two factors. The following map shows our calculations of equivalent price per ton of carbon dioxide (P tCO_2eq) emissions reduction per ton, following Börner et. al (2010).



Map 21:Equivalent price per ton of carbon from avoided deforestation (USD/tCO_2eq)

Source: own elaboration

Map 21 shows the interaction of the variables used to calculate implicit carbon price: low opportunity costs and high carbon density forest areas show the lowest carbon price, while areas with high opportunity cost and low forest carbon density are associated to high carbon prices. Highest implicit carbon prices are found in the southern LA municipalities, in particular for Mato Grosso and Tocantins. Map also shows that highest prices are associated to municipalities located within Cerrado and Pantanal biome. For municipalities located within the deforestation arc, data shows that they are located between middle and low carbon prices, with a progressive reduction while moving to the northwest, where the densest forest is located, and where lowest deforestation rates have been registered. If municipalities are organized from cheaper to expensive opportunity cost areas, they are quite different from the order that gives the opportunity cost (compare with map 12).

Using the implicit price of carbon, we can determine the accumulated quantity of avoided emissions and the associated avoided deforestation (Figure 46 and Figure 47). For the first policy, associated with the median opportunity cost for Brazil, we determined that 8,6 million hectares were prevented from deforestation. For that quantity of area, there is an associated implicit price of carbon of USD$ 6,49 /tCO_2eq. For the alternative value of opportunity cost, the associated implicit price of carbon is approximately USD $2,25/$tCO_2$eq

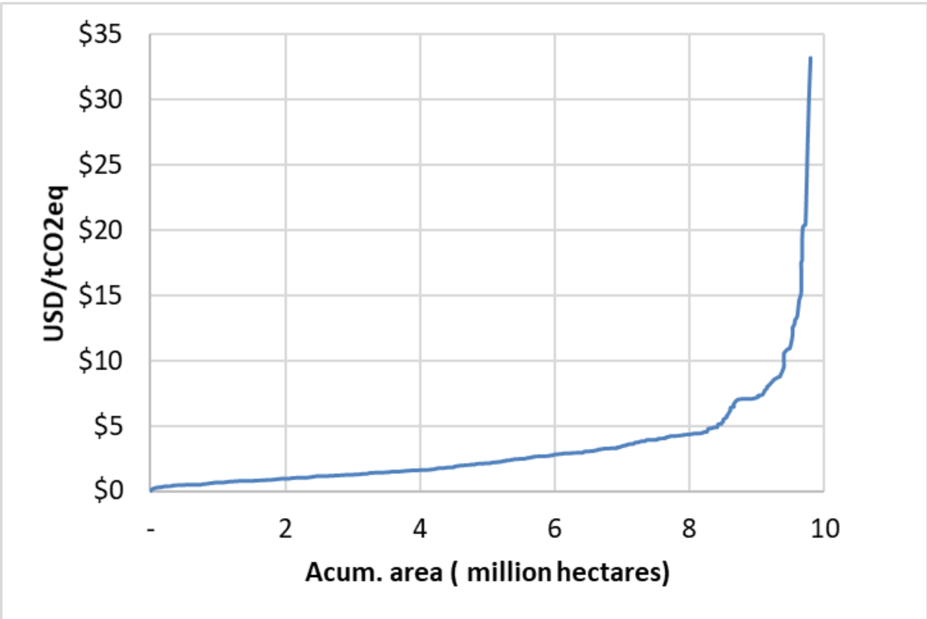


Figure 46: Implicit price of carbon and avoided deforestation

Source: own elaboration

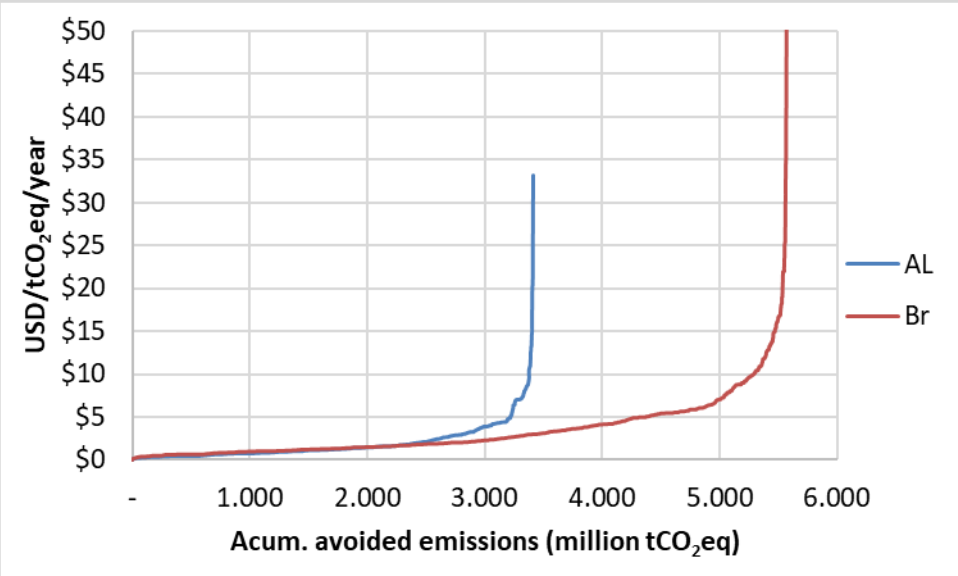


Figure 47: Emissions reduction supply curve for Legal Amazon and Brazil

Source: own elaboration

Ecosystem Marketplace reported the following international prices for REDD+ projects:

Table 26: Mean prices for REDD+ projects (2014-2017)

Year	REDD+ mean price ($/tCO2eq)
2014	4,2
2015	5,1
2016	3,3
2017	4,2

Source: Ecosystem Marketplace (2017).

The implicit price for Brazil opportunity cost policy lies above observed prices for REDD+ projects, and the policy using opportunity cost for LA, lies below observed prices. Therefore, this type of pricing policies will reach the conservation goals, only if it is possible to have prices below or equal to REDD+ market observed prices. With an associated carbon price of USD $4,2/tCO_2eq$, 7,7 million hectares could avoid being deforested, and 3.056 million tCO2eq stop being emitted.

Another interesting fact is that carbon supply curve is almost the same for Legal Amazon and for Brazil, up to USD $1,79 /tCO$_2$eq (8,4 million hectares of avoided deforestation). What this means is that Legal Amazon municipalities have an advantage over other municipalities, because they have high forest carbon stocks and low opportunity costs: higher carbon stocks, generate low implicit carbon prices, and high opportunity costs generate high implicit carbon prices. There for, municipalities within LA are very attractive for REDD+ projects.

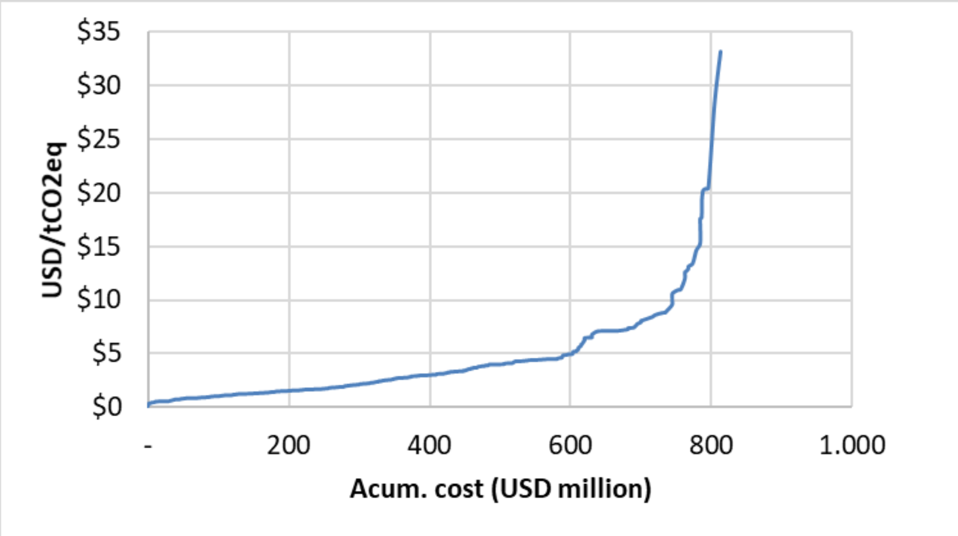


Figure 48: Accumulated costs for emissions reduction

Source: own elaboration

The associated costs for each of the policies will be: for Brazil's mean opportunity cost (USD$ 6,49 /tCO2eq), the associated cost will be USD$ 630 million, for the mean opportunity cost for LA (USD$ 2,25/tCO2eq), the associated cost will be USD $315 million.

It should be noted that the projections in this study do not consider exogenous effects, such as changes in commodity prices or reduction / change in compliance with legal regulations. Changes of this type can increase the amount of deforestation when compared to the assumed baseline here.

It should also be emphasized that it is necessary to guarantee the continuity of efforts to reduce deforestation, including public investments, which are not being considered in the present analysis. Elements such as costing the strengthening of follow-up and monitoring activities are necessary in addition to the costs and opportunities shown here.

The analysis of concrete experiences of PSA programs in Brazil, presented by Young (2016), shows that the establishment of an effective PES system must also include costs of monitoring, supervision and administration, as well as transaction costs. These aspects are important, but are often neglected, leading to numerous problems that jeopardize the program's sustainability.

Finally, it should be remembered again that the values generated are a first approximation to total PES implementation costs for forest conservation, and that future studies should be designed to deepen and refine the results, including, for example transaction costs like land tenure legalization, or measuring, verification and evaluation (MVR) costs.

4.3.3 PES scheme for revegetation and fencing

As mentioned previously, the concept of forest recovery is quite broad, ranging from a simpler understanding of the issue, where it is enough to interrupt anthropic actions so that nature regenerates, even to more demanding visions, in which it is necessary to recover the structure of the soil and promote the reintroduction of species of original seedlings that have been extinguished from the landscape.

Of course, the total cost of the project depends on the vision of recovery to be adopted, as well as chosen parameters (with or without costs of labor, transportation, administration, low or high density of seedlings). Table 27 summarizes the parameters considered and the resulting cost structure in each of the scenarios[26].

Table 27: Cost structure for reforestation scenarios

Considered costs		Scenario 1	Scenario 2
Opportunity Cost (OC)		X	X
Fencing Cost (FC)		X	X
Reforestation cost (RF)	Labor cost		X
	High seedlings density		X
	Market seedling price		X
Inputs' transportation cost (TC)			X
Administration cost (AC)			X

[26] In the first scenario, the costs related to the enclosure of the area were accounted for, plus the opportunity costs of the land. In the second scenario, the cost structure reflected, in addition to the aforementioned costs, the cost of reintroduction of the seedlings. In the second case, the costs of transportation of inputs, project management and labor costs were considered.

Regardless of the concept of "forest recovery" to be implemented, the restoration of ecosystem functions also provides monetary sacrifices to landowners where it would occur. These sacrifices result from the income that will be lost due to the non-use of these lands in agricultural activities. Thus, opportunity costs deserve to be incorporated into forest recovery costs in both scenarios.

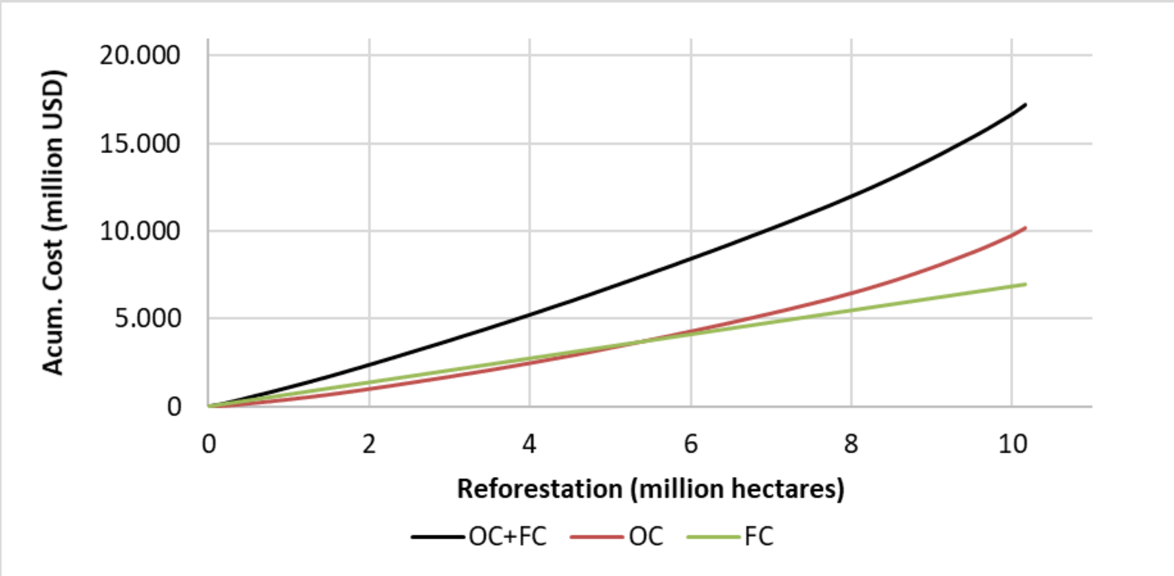


Figure 49: Distribution of forest recovery costs * (fencing + opportunity cost of land)

Source: own elaboration

In scenario 1, the results indicate that to recover the 10,1 million hectares would require R $ 17,1 billion. Of this total, about USD $10,1 billion refers to the payment of the opportunity cost of land, and the remaining USD $6,9 billion to the enclosure costs (figure 65). We can work with the more conservative hypothesis, in which the total area of legal reserve deficits would be recovered, but only a proportional area to the 12 million hectares related to the commitments assumed by the Federal Government at the time of the Paris Agreement would be recovered in the LA. LA share of total LR deficit is approximately 55,8%. If we apply that percentage to total LA deficit, the recovery area reaches 5,6 million hectares. Then, total associated cost to comply with Brazilian government commitment will require USD $7,6 billion. Opportunity costs are almost 60% of total recovery costs, then, it is a cost that must be considered, in order to have an effective strategy for policymaking. If we keep our assumption, that agricultural producers are rational, in an economic sense, the exclusion of the opportunity cost from a PES scheme, will imply that agricultural producer will keep developing its activities, as they generate higher return and don´t have a complete compensation for their activities.

Table 28: Fencing costs and opportunity cost by Federal Units in Legal Amazon.

FU	Recovery Area (ha)	Fencing cost total	Opportunity cost total	FC+OC
AP	16.270	11.201.160	10.256.681	21.457.841
RR	24.580	16.921.962	7.170.361	24.092.323
AC	79.856	54.975.497	52.115.539	107.091.036
AM	201.908	139.000.577	46.710.241	185.710.818
RO	308.244	212.205.827	308.193.945	520.399.772
TO	934.666	643.456.233	697.661.769	1.341.118.003
MA	1.162.654	800.411.506	1.046.242.176	1.846.653.682
PA	1.599.028	1.100.826.244	1.219.166.037	2.319.992.281
MT	5.837.488	4.018.729.324	6.806.348.154	10.825.077.478
LA	**10.164.694**	**6.997.728.331**	**10.193.864.903**	**17.191.593.234**

Source: own elaboration

Compliance of Legal Reserve, in the first scenario (opportunity cost + fencing costs), continue to follow the opportunity cost distribution. Municipalities with high opportunity cost and high LR deficit show highest total costs. Mato Grosso, Pará and Maranhão continue to present highest costs: $1854, $1450 and $1558 USD/ha respectively. Roraima has a cost of USD $1.688/ha, associated mainly to high opportunity cost. Lowest mean costs were calculated for Amazonas (USD $919/ha) and Roraima (USD $990/ha) states.

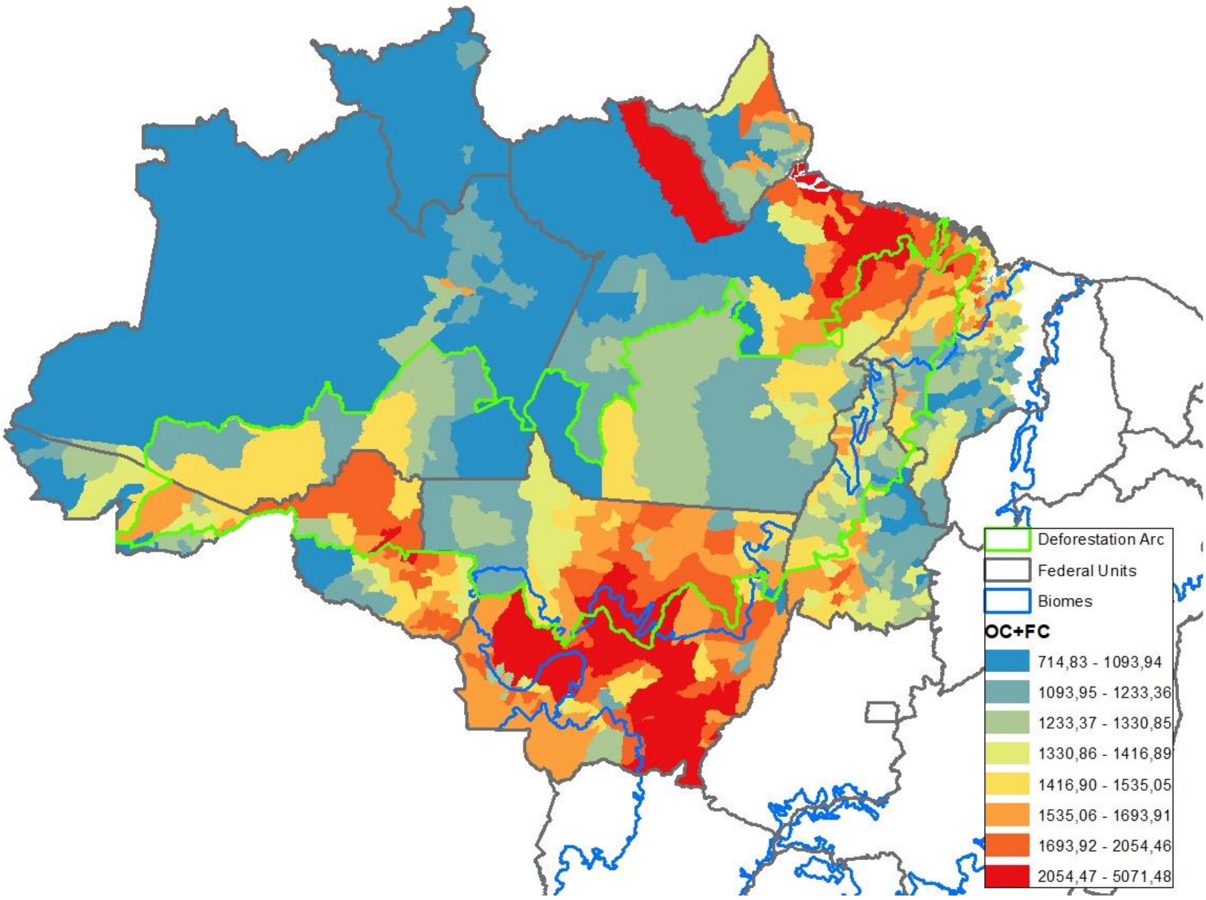
Table 29: fencing costs and opportunity costs by biome in Legal Amazon

Biome	Recovery Area	Fencing cost total	Opportunity cost total	FC+OC
Pantanal	73.402	50.532.741	81.195.597	131.728.338
Cerrado	2.467.211	1.698.513.431	3.269.290.800	4.967.804.231
Amazon	7.624.081	5.248.682.159	6.843.378.506	12.092.060.665
LA	**10.164.694**	**6.997.728.331**	**10.193.864.903**	**17.191.593.234**

Source: own elaboration

When compliance costs are analyzed by biome there are also important differences: Amazon has the largest deficit area, and a mean cost of USD $1.586/ha. Pantanal municipalities have the lowest deficit share, and an associated recovery costs of USD $1794/ha. Cerrado presented the highest recovery cost per hectare: USD $2.013/ha. Then, the cheapest areas can be found in Amazon, then in Pantanal, and the most expensive ones in Cerrado biome.

The following map shows de distribution of costs per hectare for each municipality.



Map 22: Mean opportunity cost and fencing costs by municipality in Legal Amazon (USD 2016).

Source: own elaboration

Map 22 shows that municipalities with lowest costs per hectare, are located in in the Amazon biome states: northern Amazon and Para, Roraima states; northwestern Mato Grosso state; and some other municipalities located in Acre, Rondônia and Roraima. For Pantanal municipalities, we can see that they are located between middle and middle high costs per hectare. Municipalities from Cerrado present some of the highest recovery cost, in particular for Mato Grosso state. Some interesting municipalities are located in eastern Maranhão and central/eastern Tocantins, as they report some of the lowest recovery costs. Municipalities in the first quartile for area, have a cost up to USD $1.385/ha, and generate total cost of USD $3,1 billion.

In the second scenario, we included some futures: a) cost of labor is different for every state, b) reforestation costs, includes planting costs and maintenance costs for two years; c) we used a 6% discount rate, to analyze costs on a net present value costs (Figure 50).

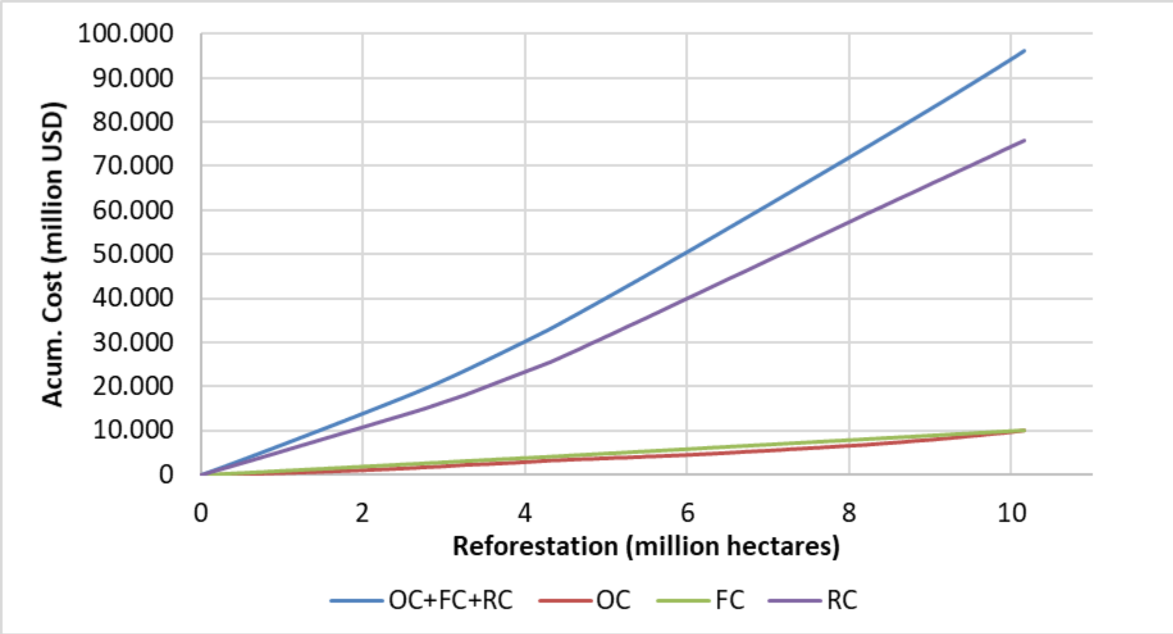


Figure 50: Distribution of forest recovery costs - Scenario 2.

Source: own elaboration

Introduction of reforestation costs (seedlings, planting and maintenance) represented an additional cost of USD $75 billion, so that total costs of forest recovery of the USD $96 billion, to attend a 10.1 million hectares' deficit . Alternatively, the federal government's commitment to recover 12 million hectares by 2030 in the country, and proportional 5,6 million hectares in LA, would result in a forest recovery cost of some USD $ 47 billion (Figure 66). Reforestation costs account for nearly 78% of total recovery costs in this scenario.

Table 30 shows that again, Federal Units with high deficit area have high reforestation costs: Mato Grosso, Para and Maranhão. A detailed analysis of different costs, planting densities, inputs' use and costs can be found in Annex 10. An important difference here is associated with seedling costs and labor costs. In particular, availability of native seedlings, and associated high cost influence recovery cost structures. In addition, labor costs vary between Federal Units, and highest costs are present where there is more agricultural activity.

Table 30: Total fencing costs, opportunity costs and reforestation costs per Federal Unit, USD 2016 in present value.

FU	Reforestation Area (ha)	Fencing cost total	Opportunity cost total	Reforestation costs	FC+OC+RC
AP	16.270	15.818.452	10.256.681	94.330.373	120.405.506
RR	24.580	23.947.555	7.170.361	142.432.026	173.549.942
AC	79.856	76.691.734	52.115.539	431.253.014	560.060.287
AM	201.908	193.947.312	46.710.241	1.134.811.397	1.375.468.950
RO	308.244	308.236.233	308.193.945	1.920.462.645	2.536.892.824
TO	934.666	901.804.868	697.661.769	4.985.924.328	6.585.390.965
MA	1.162.654	1.111.848.206	1.046.242.176	8.224.718.814	10.382.809.196
PA	1.599.028	1.545.447.821	1.219.166.037	8.819.458.927	11.584.072.785
MT	5.837.488	5.891.163.161	6.806.348.154	50.207.316.436	62.904.827.752
LA	**10.164.694**	**10.068.905.342**	**10.193.864.903**	**75.960.707.960**	**96.223.478.205**

Source: own elaboration.

Recovery costs by biome show that important differences arise again (Table 31): lowest cost per hectare were calculated for Amazon, with USD $9.277/ha, but highest cost are reported for Pantanal biome with USD $10.400/ha. Cerrado report USD $10.023/ha and mean cost for LA rises up to USD $9.466.

Table 31: Total fencing costs, opportunity costs and reforestation costs by biome, USD 2016 in present value.

Biome	Reforestation Area	Fencing cost total	Opportunity cost total	Reforestation costs	FC+OC
Pantanal	73.402	74.077.301	81.195.597	608.162.967	763.435.865
Cerrado	2.467.211	2.466.563.295	3.269.290.800	18.993.348.465	24.729.202.560
Amazon	7.624.081	7.528.264.746	6.843.378.506	56.359.196.528	70.730.839.780
LA	**10.164.694**	**10.068.905.342**	**10.193.864.903**	**75.960.707.960**	**96.223.478.205**

Source: own elaboration.

Differences in biomes and can be explained on the variables that were considered in comparison with scenario 1:

1) seedling prices for municipalities within Federal Units report important variations, for example, Mato Grosso had a rise in price from BRL $3,92/sed. to BRL $5,40/sed., that is, the reported difference between market price and bulk price is 38%; the same phenomena happen with other Federal Units, within each biome;

2) labor also has different values for each state: while in Acre (Amazon biome) mean wage was BRL $623/month, for Mato Grosso (Pantanal), average wage was BRL $1.126/month;

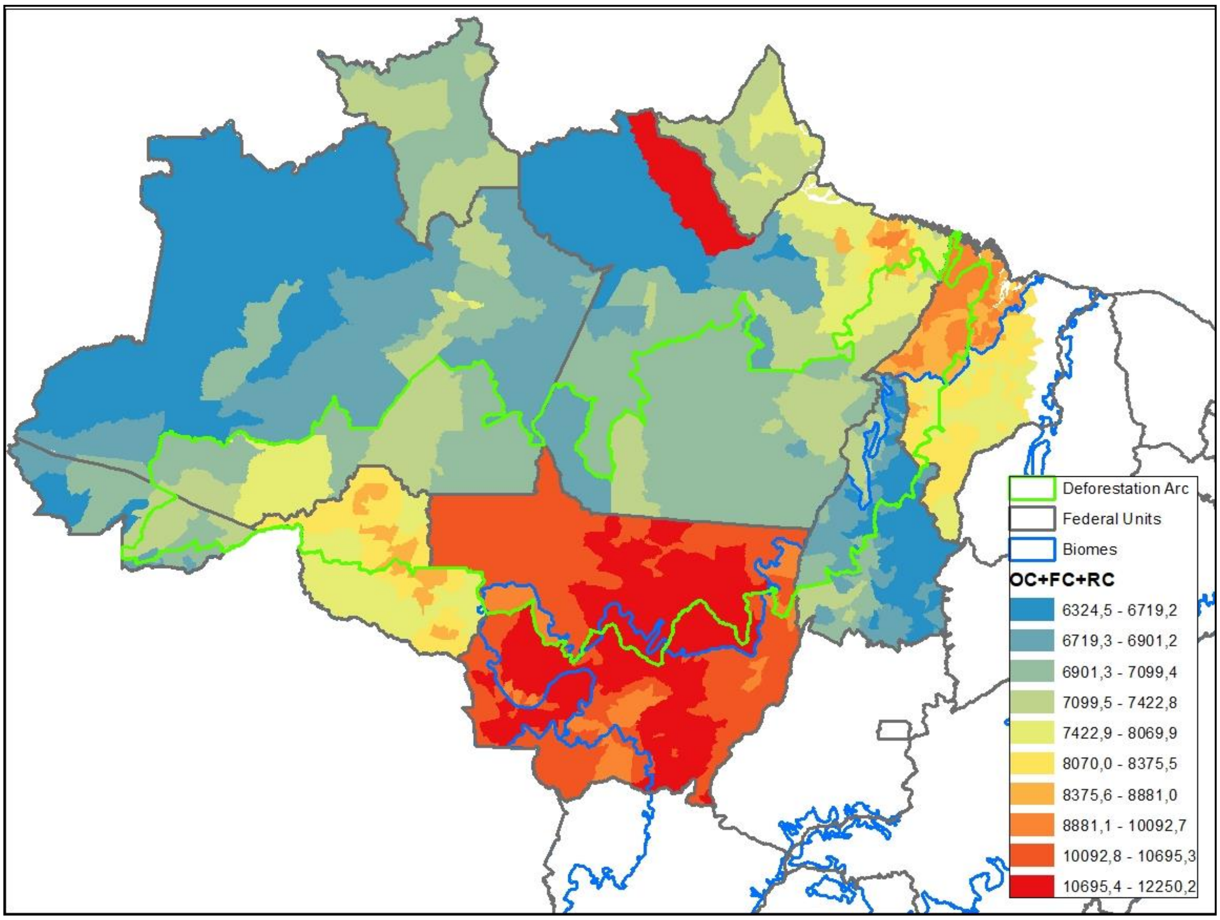
3) Input prices also have important variation across the FU: the price for herbicides fertilizers, and soil conditioners (lime) reports important variations;

4) seedling densities also vary across biomes and across scenarios: for scenario 1 seedlings density for Amazon biome was 1406 sed/ha, while for scenario 2 it was 2.500 sed./ha.;

5) labor can be understood as a contribution from the agricultural producer within the commitments of the PES scheme; then, the first scenario didn´t consider labor costs, assuming that the producer will be able to implement fencing and planting within his own labor force; for scenario 2, we assumed that labor needed is be fully payed.

The selected scenarios are considered the ones with lowest costs (scenario 1) and with highest costs (scenario 2). Therefore, any combination of inputs will lie between these two values.

Map 23 shows spatial distribution of total recovery costs (opportunity costs + fencing costs + reforestation costs). The first quartile lies below USD $6994/ha. This will approximately correspond to the two first cost classes (dark blue).



Map 23: Scenario 2 reforestation costs (OC+FC+RC)

Source: own elaboration

Map 23 shows that maximum costs is around USD $12.250/ha and minimum cost is near USD $6324/ha. Central Mato Grosso has the highest recovery costs; all municipalities lie on most expensive ranges. In Tocantins something similar happens: all municipalities lie in low cost ranges. Municipalities in Rondônia and Roraima are located in middle cost ranges, while Maranhão presents low costs. Pará, Acre and Amazon states present middle to low cost municipalities. Municipalities in the first quartile for reforested area, are below a price of USD$ 7.419/ha, with an associated accumulated cost of USD $17,8 billion.

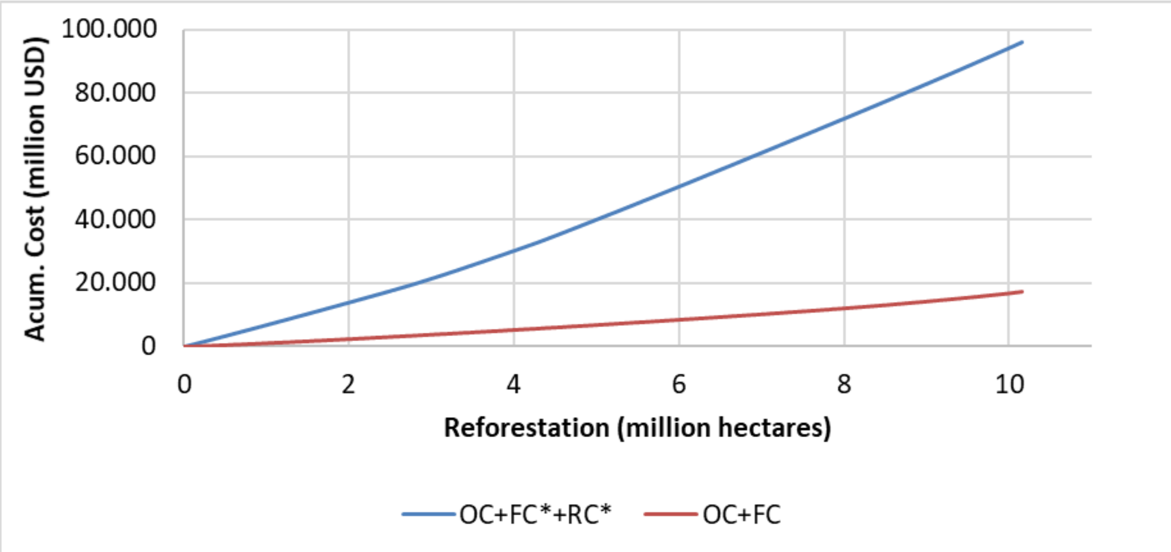


Figure 51: Comparison between Scenario 1 (OC+FC) and Scenario 2 (OC+FC+RC)

Source: own elaboration

Figure 51 shows that scenario 2 generates 5,6 times more cost than scenario 1. As stated different combinations of input prices, labor costs, seedlings density, administrative costs, input's transportation costs, among others may lie between these two alternatives. So, as you start to include different costs you may expect to have increasing costs. This graph allows generating different compliance scenarios cost. If, the government wants to achieve a 50% compliance of LR deficit (approximately 5 million hectares), the associated cost will be between 6.8 billion and 40,1 billion, depending on the different cost components that want to be covered by the proposed reforestation PES.

The reason for incorporating additional costs beside those from fencing and opportunity costs is to secure the supply of different ecosystem services from reforested/afforested areas. One particular ecosystem service relates with the potential of carbon capture that planted forests have. We used Palermo (2011) carbon capture potential per hectare per year for different reforestation species, to determine carbon stocks by planted forests. Based on carbon densities from table 13[27], we generated some results by biome and federal unit. Total reforestation of 10,1 million hectares, in the Brazilian Legal Amazon, has a potential of reducing up to 3.3 billion tCO_2eq. We assigned a carbon capture potential from reforestation, for each municipality according to their area share on a specific biome. Table 32 shows the results of summarizing municipal data by Federal Unit.

Table 32: Reforestation area, mean CO_2 capture per hectare and total CO_2 captured by Federal Unit, in Legal Amazon.

UF	Reforestation area (ha)	Total CO_2eq.	CO_2eq/ha
AP	16.270	6.469.954	397,65
RR	24.580	9.774.374	397,65
AC	79.856	31.754.653	397,65
AM	201.908	80.288.772	397,65
RO	308.244	122.490.896	392,88
TO	934.666	268.770.643	203,15
MA	1.162.654	437.345.567	274,18
PA	1.599.028	635.450.669	392,45
MT	5.837.488	1.806.869.921	262,30
LA	**10.164.694**	**3.399.215.450**	

Source: own elaboration

Maranhão, Tocantins and Mato Grosso present a lower carbon capture potential from reforestation than the other LA Federal Units. The reason for this difference lies on the assigned regeneration rates for each biome. Mato Grosso has municipalities within de Amazon biome as well as in Cerrado biome. According to Palermo (2011), carbon sequestration in Amazon is 2,7 times the one reported for Cerrado. From all Federal Units within the Legal Amazon, Mato Grosso possess the highest share of CO_2 emissions: 54%. Total CO_2 emissions stocking capacity is related with the amount of deficit area (5,8 million hectares, 57% share), rather than its carbon capture potential, which is one of the lowest (262,30 tCO_2eq/ha/year). Pará and Maranhão are in second and third place: both reported high Legal Reserve deficit, but Maranhão reports also low levels of carbon capture for reforestation activities. The lowest amount of total carbon capture capacity is associated to Amapá, Roraima and Acre states.

[27] We made an adjustment on Palermo (2011) carbon capture, in order to transform tC/ha/year to tCO_2eq/ha/year, in order to make results comparable.

Table 33: LA reforestation area, mean CO_2 capture per hectare and total CO_2 captured.

Biome	Reforestation area(ha)	CO_2eq total	Mean CO_2eq/ha
Pantanal	73.402	10.617.653	144,65
Cerrado	2.467.211	356.882.004	144,65
Amazonia	7.624.081	3.031.715.793	397,65
LA	**10.164.694**	**3.399.215.450**	

Source: own elaboration

Carbon capture from reforestation also shows differences among biomes (Table 33). Amazon biome accounts for nearly 89% of total carbon capture potential. This high share is associated with its high share of LR deficit area (75%) and is high per hectare capture capacity (397,65 tCO_2eq/ha/year), that corresponds to the highest value for a biome in Brazil.

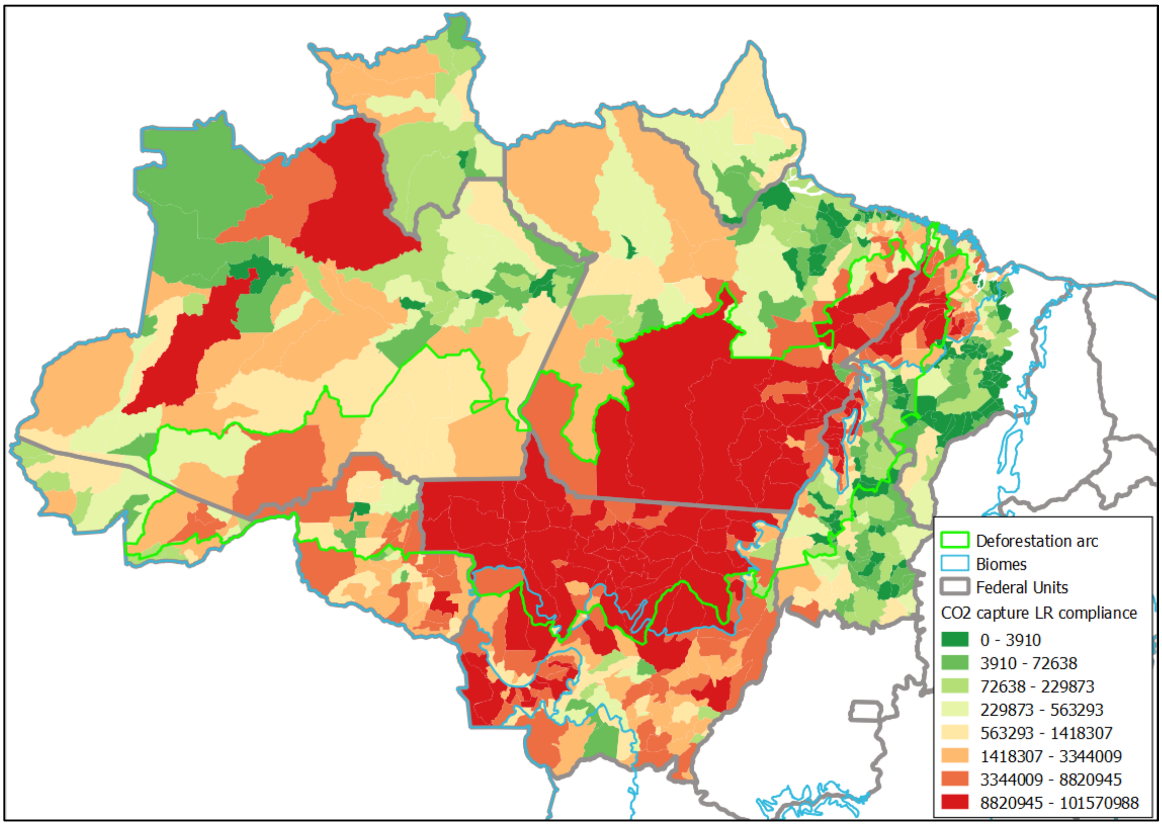
Table 34 summarizes carbon capture potential and costs for scenario 1 and scenario 2.

Table 34: Forest Code Legal Reserve compliance levels at two different recovery costs.

Forest Code Legal Reserve compliance	25%	50%	75%	100%
Area (ha)	2.568.388	5.007.018	7.628.733	10.164.694
Accumulated cost OC+FC (million USD)	3.146	6.783	11.256	17.191
Accumulated costs OC+FC+RC (million USD)	18.013	40.157	67.747	96.125
Accumulated CO_2eq capture (million CO_2eq/year)	955	1.786	2.726	3.399
Mean CO_2eq capture/year/municipality	2.280.602	2.894.835	3.660.202	3.793.767

Source: own elaboration

Map 24 shows total emissions by municipality when a 100% of Legal Reserve deficit is reached, following the New Forest Code rules. Municipalities with highest total CO_2 forest stocking are located within Mato Grosso, Pará and Amazonas. There are some other municipalities located in northern Maranhão and Tocantins.



Map 24: Carbon capture with 100% Legal Reserve compliance for New Forest Code (tCO_2eq/ha/year)

Source: own elaboration based on Soares-Filho et al. (2014) and Palermo (2011)

We can see that forest carbon capture capacity is determined by forest area deficit and associated carbon capture capacity by reforestation activities.

4.4 Conclusions

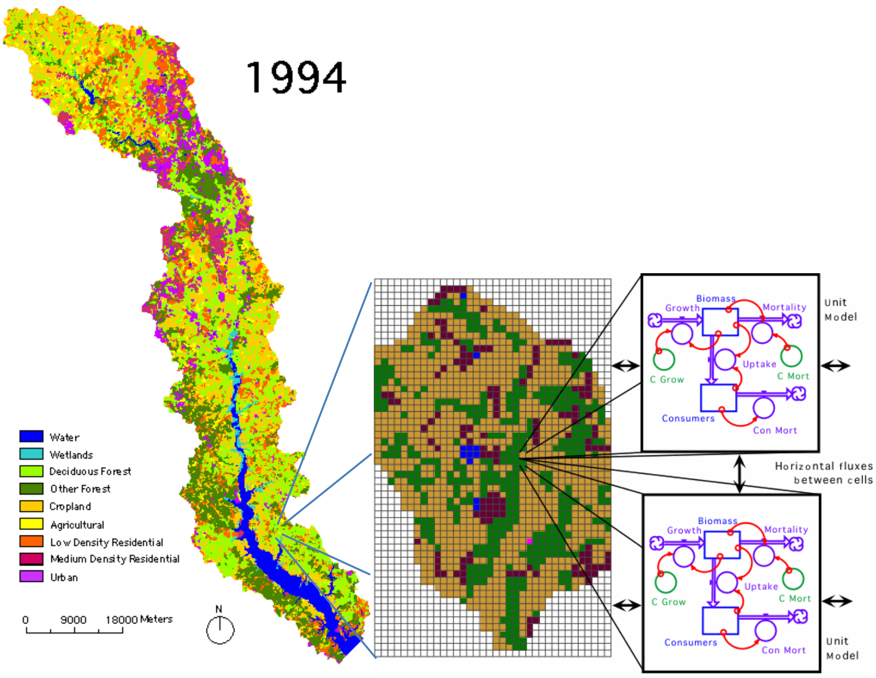
Future projected production for livestock agribusiness will imply additional deforestation, based on dependence analysis of cattle ranching expansion on deforestation, despite the advances on livestock stocking rates up to 2030. Mato Grosso and Pará states will contribute with highest amount of pastures expansion between 2015-2030 periods.

SISGEMA and Dinamica EGO deforestation projection methodologies projected different quantities of deforestation, but each one has its strengths and weakness. Dinamica Ego helped to distribute spatially deforestation, based on biophysical and some socioeconomic characteristics, but overestimate deforestation rates. Meanwhile, SISGEMA, capture recent years' trend on deforestation, then, projections were more adjusted to observed deforestation.

SISGEMA present difficulties to locate spatially deforestation, as it is a mathematical model, not a spatial model. Despite this difficulties, both projections are consistent with other studies like the one developed by GLOBIOM for the whole country.

Deforestation projections showed that Cerrado values will be higher than Amazon biome ones. This implies an important policy focus to try to design incentives for this particular biome, within the Legal Amazon, that can curve this future trend.

Despite the later result, some modelling limitation didn't allow to identify more recent trends like increase on deforestation on LA for 2015 to 2017. Limitations are related with information, and relations not include in the model. In particular, we must recognize the existence of complexity and non-linear relationships between biophysical, economic and biodiversity variables. In addition, agricultural producers sometimes do not act as rational agents, which is one of our baseline assumptions, and act more like having procedural rationality in Simon (1979) sense. To overcome these difficulties, the use of general systems theory can help to identify, characterize and generate land use models as suggested by Costanza et al. (1998). This is one of the first efforts to include non-linear relationships on different variables, to try to model land use changes for a watershed.



Map 25: Patuxent watershed land use complexity modelling for land use change.

Source: adapted from Costanza et a. (1998)

Map 25 show how it is possible to incorporate different GST modelling for different Land Use categories, represented by different cells. In previous version of Dinamica EGO, there was a functor that allows linking to Stella of Vensim (general systems theory programs), deforestation rates calculations, following non-linear relationships. Today that option is not available, but still regression modelling can still be incorporated, to include other socioeconomic variables. Another alternative is to identify each land use cell as a decision unit, based on Agent Based Modelling. Today, the National Institute of Spatial Research (Instituto Nacional de Pesquicas Espaciais- INPE), has developed a coupled model with their LUCC-ME projection model. INPE recognized that:

> *"agent based models are a promising approach for representing land use change decision processes, actors interaction, and feedbacks with the natural system (Jansen and Ostrom, 2006). But in comparison to the LuccME approach, agent-based models require more data and fi eld knowledge to create empirical models (Robinson et al, 2006), being usually applied to small area extensions"* (Aguiar et al., 2012).

An interesting approach identifying agent's objectives, rules and interactions (institutional arrangements), can be found in Câmara et al. (2011). They state that Brazilian Amazon has different institutional arrangements, that influence spatial and temporal patterns of deforestation and forests, which can be understood as common pool resources. Then, they try to identify different agents and try to model their actions, in particular they develop a landscape model, with different rules for two main agents: small farmers and medium/large farmers. Costa (2012) used a similar approach, exploring the use of agent based models (ABM) to represent land change in frontier regions, in particular applied the model to Sao Felix do Xingu, in the south-east of Pará. This municipality reported high deforestation rates during 1990´s, within the deforestation arc. He run a retrospective scenario from 1970 to 2010 to understand how public policy influenced land use change, and explore possible pathways between 2010 to 2020 years.

An interesting result from deforestation projections show that new areas will be included, as new frontier areas (following the FTT) are being incorporated. These new deforestation areas lie within the deforestation arc, and other areas at the north of Legal Amazon, in particular municipalities limiting Roraima and Amazonas states and Pará and Amazonas states. Other new interesting areas are located in southern municipalities of Amazonas state and in Acre.

Maps and graphs on different alternatives for PES on avoided deforestation and reforestation show that to define an area for a PES implementation it is possible to use biological as well as economic information (in particular opportunity cost). Implementation of a PES policy must be designed on per hectare costs, in order to incorporate cost-effective criteria, to identify priority areas. In fact, ordering municipalities from high implicit carbon prices showed cheaper areas for PES implementation, those know in the literature as “low hanging fruits”, as they are present very low payment costs, and high projected deforestation areas.

PES focused on avoided deforestation and reduction of emission from avoided deforestation (that is REDD+ projects), must take into account forest carbon stock differences. Our analysis showed that uneven distribution of carbon stocks influences on carbon implicit prices, as a measure of a Willingness to Accept (WTA), for forest conservation activities.

Opportunity cost generated by Young (2016), is also unevenly distributed, so, it generates different cost-effective areas, when we use it to identify priority areas for promoting deforestation reductions or reforestation activities. Even though this data was calculated for each municipality in Brazil, policies should try to go one step forward, and start to make more detailed analysis using information from the Rural Environment Registry (Cadastro Ambiental Rural, CAR), to identify WTA limits as a first step to formulate PES schemes that recognize heterogeneity among agricultural producer, which are the main users of this schemes.

Different factors contributed to differences between prioritized regions for a reforestation PES: seed costs (normal vs. low price), seedlings (low density vs. high density), different labor cost, inclusion / exclusion of transport and administrative costs. So, design of effective policies should take into account these costs. There are other additional costs not included in this study, like land titling costs or monitoring costs, which constitutes one part of transaction costs, but that must be incorporated in future PES design.

Absolute values of legal reserve deficit up to 2013, show an interest relationship with projected deforestation (up to 2030): as deforestation increases in forest frontier municipalities, legal reserve deficit starts to consolidate; later, this settled frontier, exhibits highest forest deficits to comply with legal reserve requisites, as new deforestation areas continue to expand to other municipalities in the new forest frontier, and generating new deficits to comply with legal reserve requisites.

We identified several relevant costs for implementing reforestation strategies and PES mechanism. It is important to identify ways to reduce some of these costs with strategies such as:

a) Reduce acquisition costs for seedlings and wholesale purchases or encourage seedling generation processes by the projects themselves or even increase the number of seedling companies in areas of interest for recovery.

b) Labor costs have an important influence on total costs when considering maintenance activities. It is therefore essential to establish schemes to share such costs with owners of areas identified as priorities for recovery processes, so that they can receive the costs of inputs, transportation and administration.

c) When considered together, enclosure costs and recovery costs showed that the need for investments was high. Thus, it is necessary to identify strategies to reduce those costs and reach a greater amount of area for recovery.

d) There are projects that do not include input's transportation costs and administration costs. The inclusion of those costs allows entities or organizations that are willing to administrate forest recovery projects to charge their operating costs, allowing the possibility of promoting public-private partnerships that do not generate disadvantages for any of the involved parties, and can reduce implementation costs.

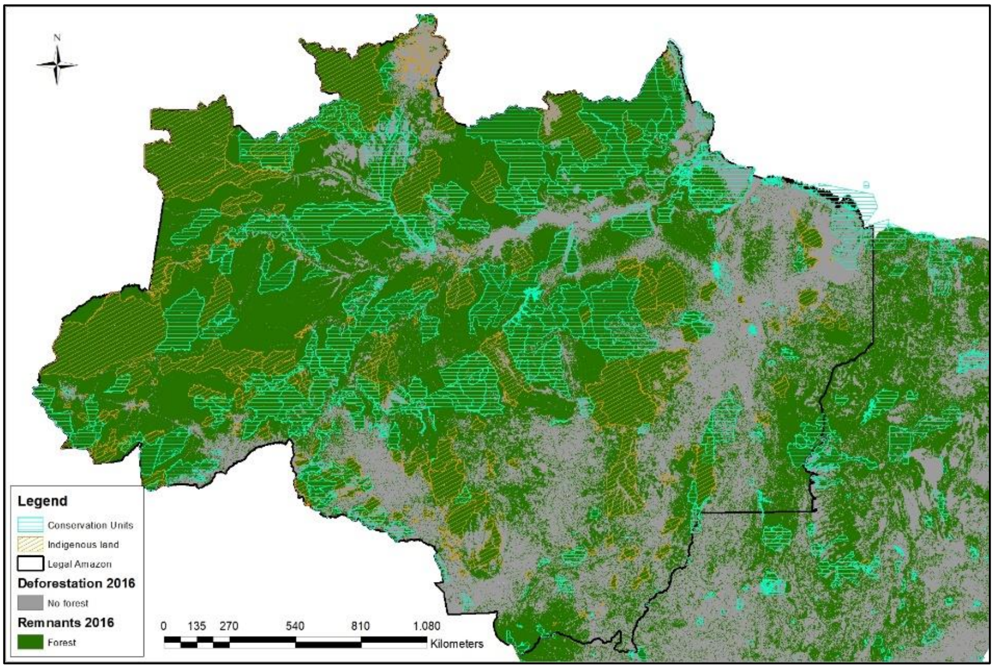
It is evident that a reforestation PES should also include the opportunity costs of land, as discussed in the previous chapter. This means that the cost of recovering forests, once destroyed, is much higher than those intended to prevent deforestation. This situation gives us a very important result: deforestation prevention is a cheaper strategy than reforestation promotion. Recovering of 10,1 million hectares to comply with Legal Reserve in the Legal Amazon will cost between USD $17 to $95 billion, while avoiding 9,7 million hectares cost USD $22 billion for a 10-year period.

The inclusion of opportunity costs allows us to have a medium and long term vision of interest areas, since in theory this payment covers the annual revenues of the areas in anthropic uses during the life of a project, which in our case was planned for 15 years.

An important topic to bear in mind is how to locate specific areas for reforestation. From biological sciences, we can explore the alternatives of locating these areas through biological corridors. Biological conservation corridors can be defined as:

> *"biologically and strategically defined subregion space, selected as a unit for large-scale conservation planning and implementation purposes. In this space, conservation action can be reconciled with the land-use demands of economic development freed from the need to find viable solutions within the confines of existing and often small protected areas and their buffer zones. (...) the concept of biodiversity conservation corridor developed here adds explicit biodiversity conservation targets to the overall process of corridor planning and implementation"* (Sanderson et. al, 2006)

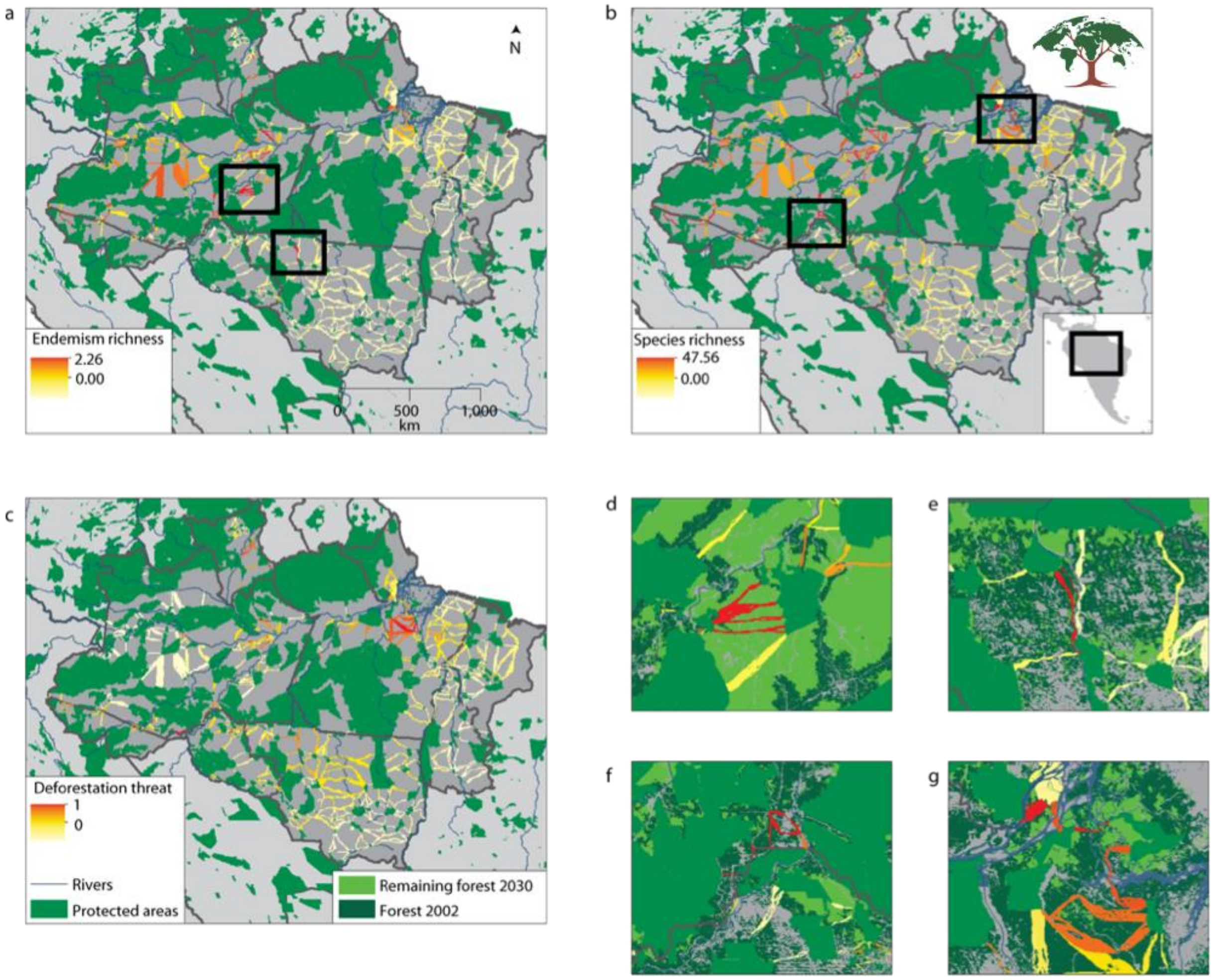
Some of the elements of a biodiversity conservation corridor are: a) a protected area system; b) connectivity network; c) compatible land uses and human settlements (Sanderson et al, 2006). The definition of biological corridor implies de necessity of different protected areas. Within this category it is possible to include Conservation Units, Indigenous Lands, and private preserves (RPPN). For the Legal Amazon, these areas are fundamental for forest and biodiversity conservation.



Map 26: Conservation Units, Indigenous Lands and forest remnant 2016.

Source: IBGE base and Dinamica EGO deforestation projections.

Map 26 shows that there is an important quantity of forest remnants inside Conservation Units and indigenous lands. These areas can be the basis for a biological conservation corridor. Then, the next step is to define connectivity network areas. A large scale exercise was carried out by Woods Hole Research Center, defining conservation corridors with several objectives: a) avoiding deforestation by preserving carbon stored in vegetation between protected areas, b) provide an opportunity to mitigate the effects of land use and climate change on biodiversity; c) maintain habitat connectivity across landscapes (Goetz, Laporte and Jantz, 2016). This proposal shows that it is possible to make a balance between several ecosystems services at the same time. The following map shows the proposed conservation network.



Map 27: Proposal of connectivity network and associated benefits (biodiversity and deforestation) for the Legal Amazon.

Source: Goetz, Laporte and Jantz (2016).

Map 27 shows that there is an important connection between future deforestation areas (deforestation threat), reforestation areas to increase connectivity and biodiversity conservation.

In addition, in accordance with SISGEMA and Dinamica EGO projections, they show that deforestation areas will continue to expand to 2030, as can be seen in previous map on the following insets: Madeira River (d), in northern Mato Grosso (e), on the border of Rondônia (f) and in Pará at the mouth of the Amazon River (g). SISGEMA and Dinamica Ego have shown how much, where and at which costs deforestation is going to occur. So, future next steps relate to working on designing biological conservation corridors to establish a PES policy that can prioritize areas that can provide multiple benefits at the landscape level, as shown by the previous exercise.

Avoiding deforestation generated two direct benefits: maintenance of provisioning services from forests and reducing CO_2 emissions. There are some other benefits that we didn't account in this work but are very important in terms of biological conditions and impact on human welfare, and associated to identified reforestation and avoided deforestation areas. Young (2016) reported that avoided deforestation can reduced soil erosion in nearly 273 million tons of soil, if all deforestation is avoided in the Amazon biome, using SISGEMA projection. When complying with Legal Reserve in the Amazon biome, erosion reduction can be up to 204 million tons.

This information finally, takes us to a key aspect: trying to bundle ecosystem services provided by reforestation and avoided deforestation. ES bundling can be defined as "a set of associated ecosystem services that are linked to a given ecosystem and that usually appear together repeatedly in time and/or space" (Berry et al., 2016). When trying to bundle ecosystem services one must take into account that there are possible synergies and trade-offs. A synergy occurs when the use of one service increases benefits supplied by another, while trade-offs happen when the use of one service decreases the benefits supplied by another ES, today or tomorrow (Berry et al., 2016). The information presented on priority areas for deforestation and reforestation show that there might be a possibility of bundling services at the forest frontier. In the frontier, deforestation is increasing and Legal Reserve deficits are increasing, in the presence of significant forest remnants. It is possible then to generate conservation agreements to avoid deforestation, where reforestation of LR deficit areas can coincide spatially in the same property or neighboring properties. In this way, we can find a synergy that allows bundling these two services. In contrast, this situation if more difficult in remote areas or in settled areas, where, there are few LR deficits and low deforestation, in the first case, or high LR deficits, but very low deforestation rates, as a result of reducing forest remnants. In these two cases, bundling services will not be a good alternative as services don´t seem to show synergies. Some additional difficulties must be solved after identifying if bundling services is possible:

a) Policy failures can arise if there is uncertainty of service provision of if there is a knowledge gap on ES functioning and provision (Berry et al., 2016). This situation is true, in particular for biodiversity conservation, as there are some knowledge gaps and there is still interactions that are no linear and need to be understood before a bundling policy is proposed.
b) ES provision verification at local level is essential to avoid policies promoting undesirable results (Berry et al., 2016). In the case of Legal Amazon, if trying to bundle ES provided by deforestation and reforestation, within the remote area (following the Forest Transition Theory), can potentially generate an incentive to promote deforestation of cheap areas, to start reforestation activities to receive a PES[28]. We identified that reforestation implies higher costs, in comparison with avoided deforestation costs, because the later only take into account low opportunity costs in remote areas[29], while the former includes fencing and recovery costs. Following that agricultural producers are rational agents, they will perceive that PES for reforestation is higher than PES for deforestation. Then, the logical result is deforestation of primary forests to establish reforestation activities and receive a higher PES. All this in the existence of high verification costs, for remote areas.
c) Bundling of services under a single credit type may require buyer to purchase services they do not want (Coria et al., 2014). For LA, deforestation and associated carbon dioxide emissions represent a ES that has global effects. That is, any buyer interested in this service can get Certificate of Emission Reductions (CER’s), but maybe not interested in paying for soil erosion reduction from reforestation activities to comply with Legal Reserve deficit, which is an ES that is local not regional.
d) When bundling ES it is possible that this new bundle does not meet regulatory requirements (Coria et al., 2014). To overcome this situation, there is a need of an ecosystem services accounting system that has the ability of accounting for bundled ES at a specific jurisdictional limitation, but later can sell appropriate specific unbundled services to interested buyers. A great opportunity arises with the Environmental Rural

[28] We assumed that the received PES will be the highest amount between avoided deforestation and reforestation.
[29] Assuming homogenous high forest carbon density distribution in frontier areas.

Registry (Cadastro Ambiental Rural - CAR), as this is a tool that will map every property in Brazil. With this information it will be possible to identify different ES baselines and alternative PES policies to promote different ES.

5. CATTLE RANCHING, METHANE EMISIONS AND INTENSIFICATION THROUGH SUSTIANABLE CATTLE RANCHING

Agriculture and livestock are among the main responsible for changes in land use in all modes, and especially in Brazil (MCT, 2013; Ramankutty et al, 2007). The tendency is that this demand for food increases in the last years with the population growth, causing more conversion of native vegetation in pastures, mainly for livestock.

Traditional / extensive livestock farming is one of the main factors for the expansion of deforestation in the Amazon as presented by Alvarenga Jr. (2014). Therefore, the study by GIZ (2011) shows that the Action Plan for Prevention and Control of Legal Amazon Deforestation (PPCDAm) should seek the sustainable production of livestock, since it is one of the important factors for reducing deforestation in the Amazon

The suppression of areas of native vegetation for animal production does not only cause loss of biodiversity, but also generates greenhouse gases through enteric fermentation by livestock. Currently, enteric fermentation is the largest cause of greenhouse gases in the country, corresponding to 20% of total emissions in 2012 (MCT, 2013).

With the objective of increasing the demand for food and reducing the environmental degradation caused by deforestation, it is essential to think of productive systems with which less hectares are used per kilo produced. According to the literature (Strassburg et al, 2011, Strassburg et al, 2015, Bedasa et al, 2012, Soares-Filho et al, 2015, Demarchi et al., 2006), intensification of livestock farming is an alternative with important potential since pastures would be released to other land uses such as forest restoration or agriculture, resulting in an increase in efficiency in food production. As FAO (2010, 2013) studies argue, current pastures are still at a lower level of potential if livestock-crop-forest integration systems are adopted.

The high costs of intensifying livestock can be seen as hindering their viability. However, as presented in this report, there is a return to the rural landowner who in a few years will earn more than the costs, which justifies payment in the very short term.

The economic instrument of Payment for Environmental Services should be seen not only as a reward to those owners who have historically presented good agricultural practices or significant native vegetation but also as an important land-use change factor. Thus, the study by Agostini et al (2003) shows that PES can be based on different soil indices, with the highest index being the primary forest (REDD), while other soil uses have lower indices. From this, there is a greater approximation with respect to the total economic value of the environmental services provided by sustainable livestock. For this, the PES should provide not only financial support, but also technical assistance, especially in the specific case of intensification of livestock.

Extensive livestock areas present a low opportunity cost in the country, as presented in Report 3 of the present study, and is therefore one of the first activities to be impacted in a payment for environmental services project.

Environmental services payment projects that encourage higher-yielding land uses, related to increased provision of environmental services, occur in different Latin American countries such as Colombia (Zapata et al, 2013, Pagiola et al, 2014), in Nicaragua (Ibrahim et. al, 2007).

The joint action of different actors such as the Ministry of Environment, Agriculture, civil society, international institutions such as the World Bank, among others, is necessary for the promotion of public policies, since this policy would favor different segments.

5.1 Understanding drivers of change

Emissions of methane from livestock sources are of great importance in Brazil, but are often ignored in exercises that estimate emissions variations due to changes in land use. This section presents a methodology for estimating the reduction of methane emissions from bovine origin if better livestock management practices were introduced.

In order to do so, we present the current Brazilian cattle ranching scenario and then estimate the total methane emission (CH_4) from the enteric fermentation, describing the methodology, hypotheses adopted and database (mainly the Municipal Livestock Production Survey - PPM, of the Brazilian Institute of Geography and Statistics - IBGE). Finally, emission reductions are estimated if there is a PES that can induce the intensification of cattle ranching.

Brazil has the largest commercial herd of cattle in the world, with more than 210 million heads in 2013 (IBGE, 2014), and the second largest herd, behind only India (MAPA, 2014). Beef production has expanded rapidly in Brazil in recent years, stimulated by domestic and foreign demand, which grew particularly in emerging markets, with Russia the largest importer. According to the annual data of Municipal Livestock Production - PPM (IBGE, 2014), the Brazilian cattle herd grew steadily, but regionally differentiated (Figure 47). While in the regions where the activity has developed historically before (South, Southeast, Northeast), the herds of the North (Amazon biome) and Central West (predominantly Cerrado biome) were stabilized or even decreased (in absolute values). Pantanal had grown rapidly, along with the industrial slaughtering capacity, due to the expansion of the agricultural frontier in the two regions (Alvarenga, 2014).

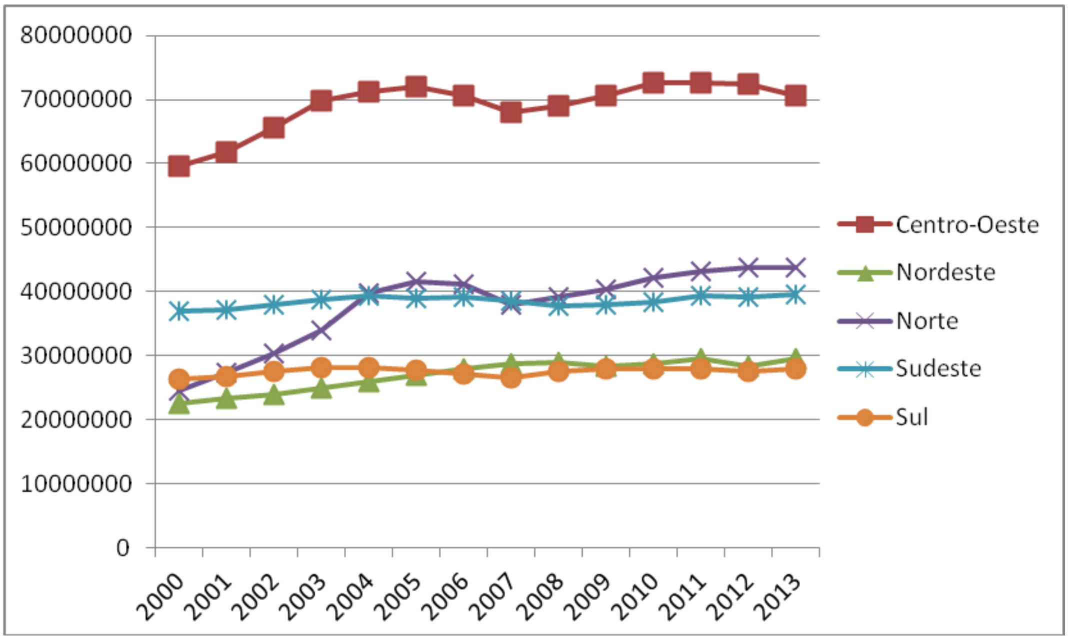
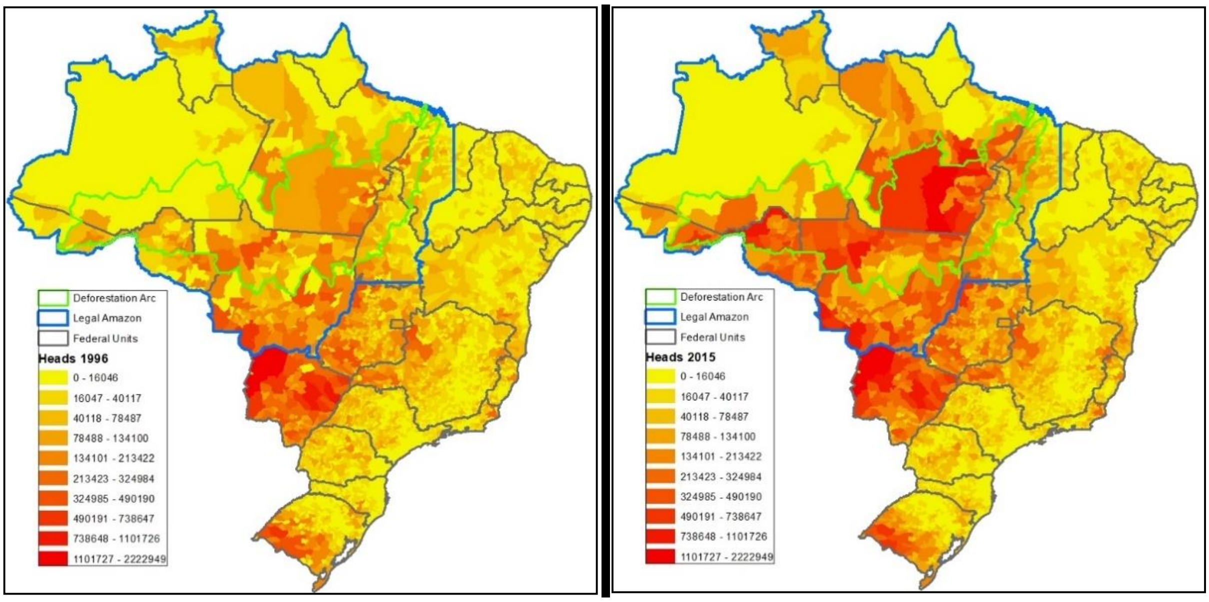


Figure 52: Cattle herd evolution by region in Brazil.

Source: own elaboration based on yearly data (2000-2013) from Produção Pecuária Municipal - PPM (IBGE, 2014).

Figure 52 shows that the cattle herd has been growing in Brazil, mainly in the North region. In contrast, in the South and Northeast, the number of cattle has stabilized in recent years. Consequently, the importance of methane emissions from the cattle herd has also increased. It should be emphasized that the ton of methane causes greater effects when compared to tCO_2eq. In the present study, the conversion defined by the IPCC (2013) is used in which 1 ton of CH_4 corresponds to 34 times the ton of CO_2eq.



Map 28: Evolution of cattle heard in Brazil and Legal Amazon 1996-2015.

However, with the increase of the herd and reduction of emissions due to changes in land use, mainly due to the reduction of deforestation in the 2000s, the share of agricultural sector emissions increased to 35% in 2010 (MCT, 2013), currently this sector is the largest emitter of greenhouse gases in Brazil (Figure 53).

Source: based on data from IBGE (2014)

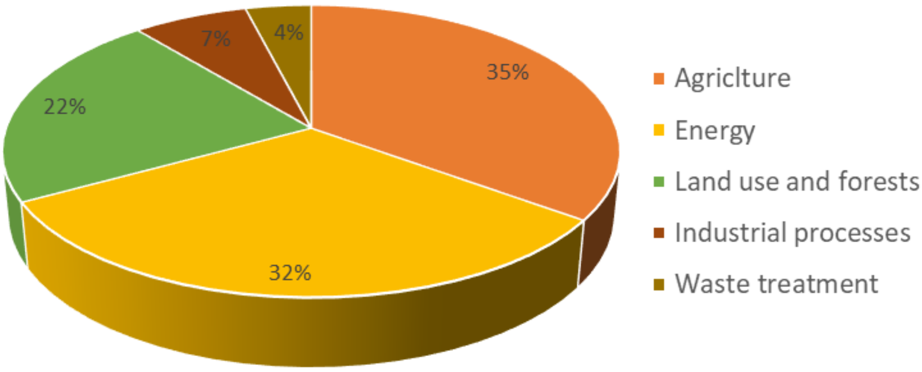


Figure 53: CO_2 emissions by type of economic activity in 2010

Source: MCT (2013)

Greenhouse gas emissions in the agricultural sector come from the following activities: enteric fermentation of livestock, management of animal wastes, agricultural soils, rice cultivation and burning of agricultural residues. The gases emitted by the sector are methane (CH_4) and Nitrous Oxide (N_2O) with high degree of impact to the methane. For the year 2010, methane emissions represented 63% of total emissions from agriculture and 22% of total emissions from Brazil.

Emissions from this sector are dominated by methane emissions from the enteric fermentation of cattle, which is the only GHG emission emitted by livestock treated in this study. In addition, we observe the evolution and participation of each economic activity, within the agricultural sector, in the emission of greenhouse gases in Brazil.

That is, enteric fermentation was the most important emitter within agricultural emissions. Most of methane from enteric fermentation comes from beef cattle (75%), a value higher that from dairy cattle (Figure 69).

Table 35 shows the evolution of GHG emission by agriculture sector.

Table 35: Brazilian agriculture's sector emissions by main activities 1990-2014

Sector	1990	1995	2000	2005	2010	2014	Var. 1995-2005	Var. 2005-2014
AGRICULTURE	**287**	**317**	**328**	**392**	**406**	**423**	24%	8%
Rice cultivation	9	11	9	10	10	10	-9%	3%
Enteric fermentation	173	188	196	235	234	237	25%	1%
Manure management	12	13	14	15	17	19	14%	21%
Crop residues burning	3	3	3	4	5	4	15%	13%
Cultivated soils	90	101	106	127	140	153	26%	20%
Direct	57	64	66	80	88	96	25%	20%
Organic waste application	5	5	5	5	7	7	8%	29%
Animal waste deposition in pastures	40	44	44	52	53	53	19%	2%
Synthetic fertilizers	3	4	7	9	11	15	93%	76%
Crop residues decomposition	5	6	7	9	12	15	47%	71%
Organic soils	4	5	5	5	5	5	4%	4%
Indirect	33	37	39	48	52	57	29%	20%
Atmospheric deposition	7	8	8	10	10	11	28%	18%
Leaching	26	29	31	38	42	46	29%	21%

Source: SEGG (2016)

Within agriculture, enteric fermentation accounted for 60% of total emissions in 1990 and 56% in 2014, while cultivated soils accounted for 31% of total sectorial emissions in 1990 and 36% in 2014. In agricultural soils, most of de activities relate with cattle ranching activities: degraded pastures, animal manure, use of synthetic fertilizers. 75% of enteric fermentation methane comes from beef cattle (Figure 54), which is higher than emission from other cattle like swine, chicken and others. Therefore, we can conclude that in the agriculture sector, cattle ranching activities contribute with a high share.

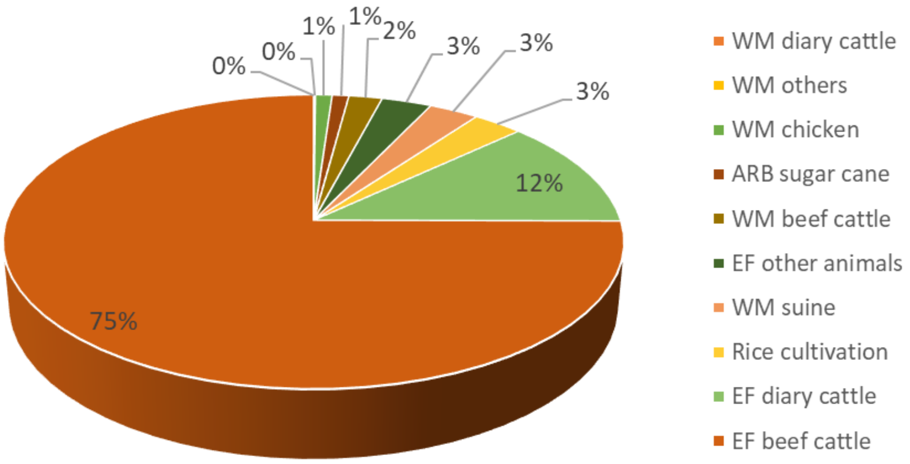


Figure 54: CH_4 Emissions' share per agricultural activity (2010)

Source: MCT (2013).

WM= waste management; EF= enteric fermentation; ARB= agriculture residues burning.

5.1.1 Key performance indicators

Selected indicators for identifying the BAU and SEM scenarios are the following:

- GHG emissions, but specifically methane (CH_4) emissions
- Pastures liberated as implementation of livestock intensification
- Costs and benefits associated with livestock intensification implementation.

Deforestation and reforestation rates are fundamental to understand evolution of Land Use Changes throughout time. Deforestation is a very important indicator because it is being directly monitored by several government organizations, in particular by Spatial Research National Institute (INPE). In addition, it has specific international government commitments: during 2015, Brazil presented it´s Intended Nationally Determined Contributions (INDC), and as part of these commitments, a zero illegal deforestation target was set for 2030[30]. It is important to remember that the initial date for zero illegal deforestation was previously set to2015. In addition, the Legal Vegetation Act (Lei 12651/2012) set a 12 million hectares' goal for reforestation. For the agricultural sector, it was set a goal to restore 15 million hectares of degraded pastures and establish 5 million hectares of integrated cropland-forestry-livestock systems (see chapter on policy analysis).

[30] http://www.wri.org/blog/2015/09/closer-look-brazils-new-climate-plan-indc

In terms of GHG emissions, the Government of Brazil established an emissions reduction target of 37%, below 2005 levels by 2025 (1.300 $MtCO_2eq$) and a 43% reduction target by 2030 (1.200 Mt CO2eq). The establishment of a PES scheme can influence in the achievement of these goals.

5.1.2 BAU scenario

We multiply the bovine herd by the emission factor, both information by municipality, type of livestock (young, male and female) and purpose (dairy, cut and work), to determine cattle ranching annual methane (CH_4) emission by municipal between 2000 and 2013 (Figure 55).

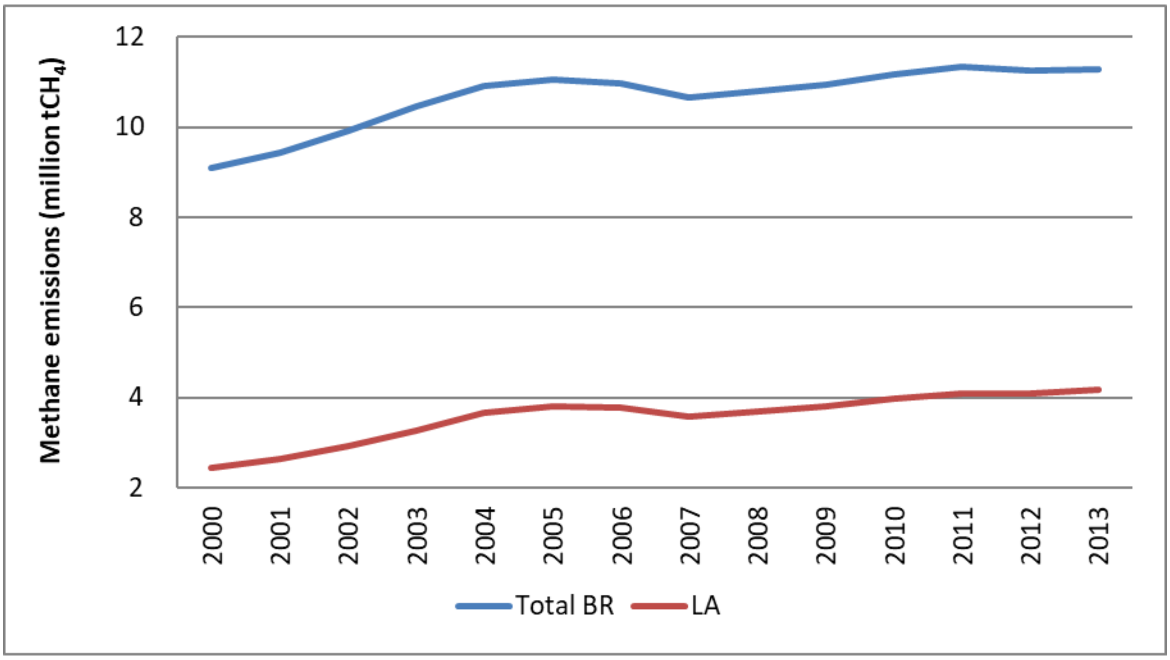


Figure 55: Annual methane emission from enteric fermentation for Brazil and Legal Amazon (2000-2013)

Source: own elaboration based on IBGE (2014).

Table 36: Comparison between methane emissions from enteric fermentation (million tCH_4)

Source	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GEMA/UFRJ	9,0	9,4	9,8	10,3	10,8	11,0	10,9	10,6	10,7	10,9	11,1	11,3	11,2
SEEG	9,0	9,4	9,7	10,2	10,7	10,9	10,8	10,2	10,4	10,6	10,8	10,9	10,9
Difference	0,1%	0,0%	1,1%	1,2%	1,1%	1,0%	1,0%	3,8%	3,5%	3,2%	2,9%	3,8%	3,0%

Source: own calculations and MCT (2014)

At an aggregate level, estimated Brazilian emissions accounted for 9 $MtCH_4$ in 2000 and grew up to 11,5 $MtCH_4$ in 2013[31]. Legal Amazon methane emissions from cattle ranching accounted for more than 2 $MtCH_4$ in 2000 and nearly 4 $MtCH_4$ in 2013. Emissions grew steadily until 2005, had a small decrease in 2006 and 2007, and continue to grow up to 2013. Table 36 show that our estimates are close to those presented by MCT (2014), despite the use of different methodologies.

Figure 56 shows the emissions disaggregated by Region. The central-western region of the country, where a large part of the agricultural frontier that extends to the North Region is located, is the most responsible for emissions of bovine methane (33%). This result is close to that obtained in other studies (Bustamente et al, 2009). The increase in emissions in the North Region and the decrease in emissions in the Southeast Region reflect the variation in the size of the herds: the expansion of the agricultural and livestock frontier pushes cattle ranching to the North, while being expelled from the consolidated areas in the Southeast, Possibly by substitution in land use for more productive crops or, conversely, by the decline in support capacity in depleted areas.

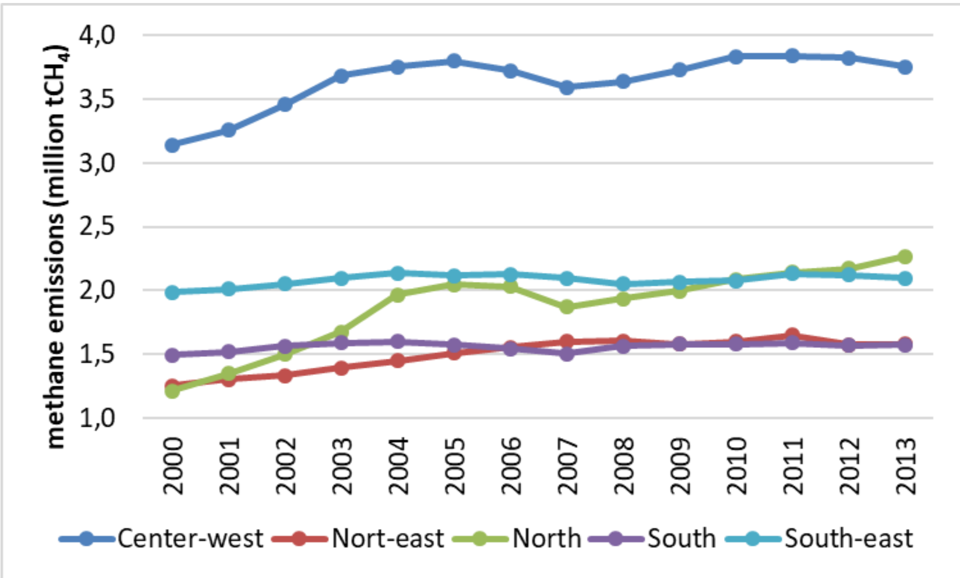


Figure 56: Yearly methane emission from enteric fermentation, by Region (2000-2013)

Source: own elaboration based on IBGE (2014)

[31] According to the latest report by the IPCC AR5, the 100-year conversion factor for global warming potential (GWP) for methane has been updated, shifting from 25 in AR4 to 34 when considering carbon climate feedback. Therefore, to perform the conversion between tCH_4 to tCO_2eq, the IPCC AR5 factor was used.

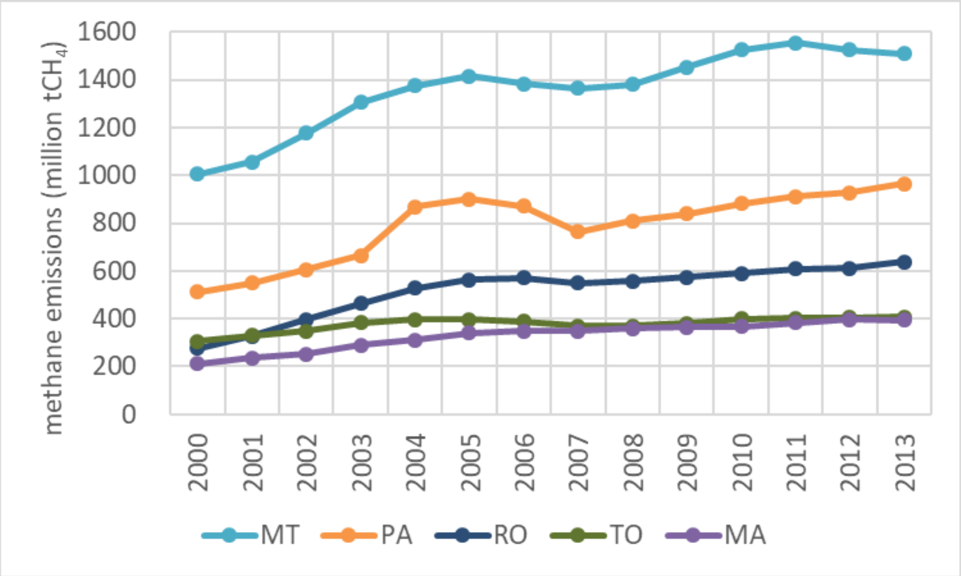


Figure 57: Methane emissions from enteric fermentation by Federal Unit (2000-2013)

Source: own elaboration based on IBGE (2014)

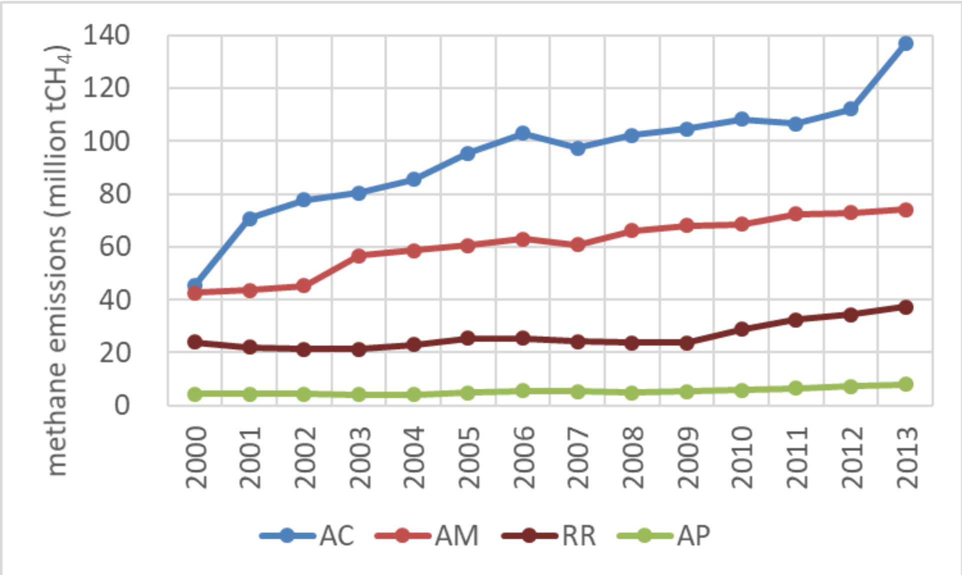
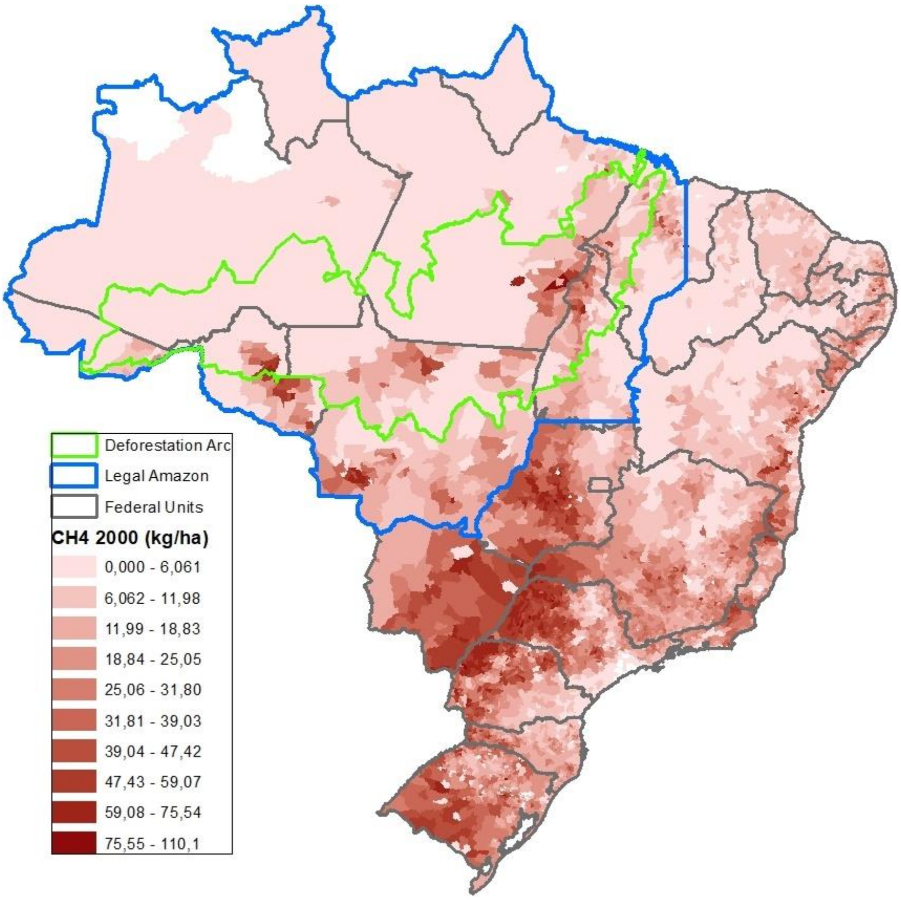


Figure 58: Methane emissions from enteric fermentation by Federal Unit (2000-2013)

Source: own elaboration based on IBGE (2014)

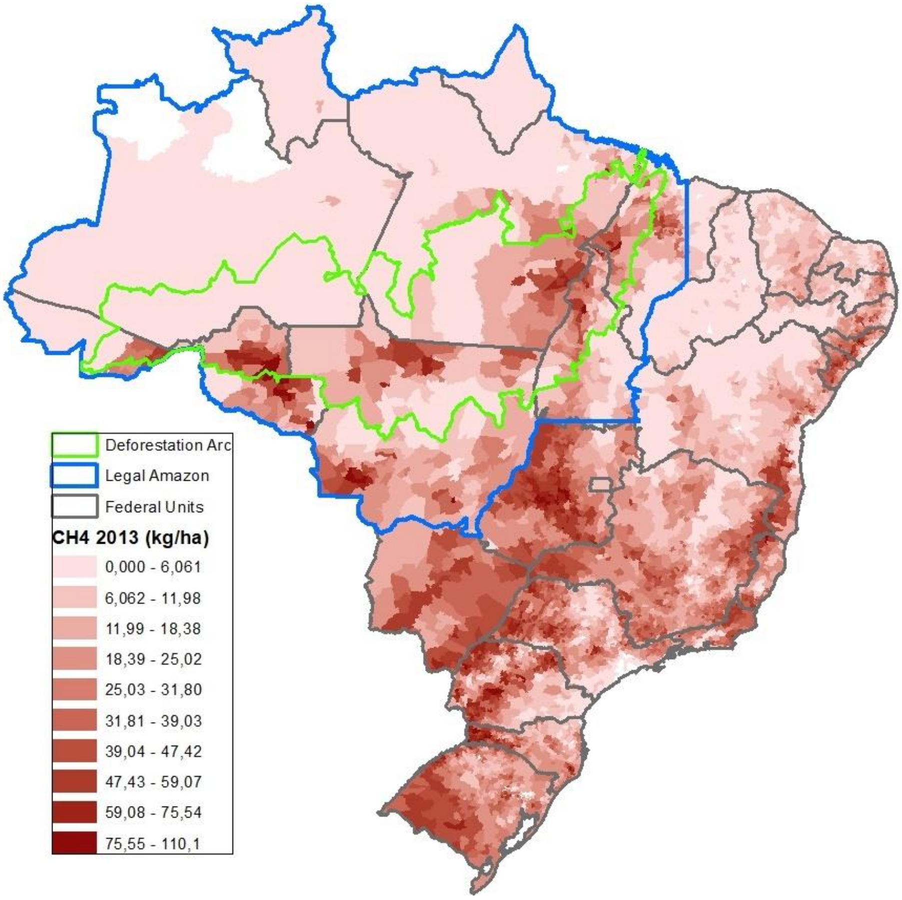
Figure 57 and Figure 58 show that Mato Grosso, Pará and Rondônia, presented the highest share on emissions from enteric fermentation. This is a continuous situation and it is expected that this three states continue this trend for the next years. Meanwhile, Amapá, Roraima, Amazonas and Acre presented the lowest enteric fermentation emissions. This situation is related with the amount of total herd in this states, and with the stocking rate that municipalities in these states show.

Map 29 and Map 30 show the evolution of bovine methane emissions over time (2000 to 2013). As expected, the expansion of livestock from the Center-West Region to the North Region has generated an increase in methane emissions, especially in the Deforestation Arc.



Map 29: Methane (CH_4) emissions from enteric fermentation by municipality area (2000) for Brazil and Legal Amazon.

Source: own elaboration



Map 30: Methane (CH_4) emissions from enteric fermentation by municipality area (2013) for Brazil and Legal Amazon.

Source: own elaboration

A PES policy should consider how it could influence both cattle management and agricultural activities. Agricultural production has been expanding, in particular in the Legal Amazon, being one of the main vectors of deforestation and emission of greenhouse gases in the country. It can be considered that livestock farming established in some Brazilian municipalities is mostly of low profitability, as evidenced from the opportunity cost of land. Thus, with the objective of transforming livestock production into an environmentally and economically efficient activity, we evaluate the effect of livestock intensification on methane emissions, based on the difference between the extensive/traditional production and intensive/confinement.

5.2 Understanding biophysical impacts: BAU vs. SEM scenario

IBGE (2006) estimated confined cattle heads in about 3 million animals for Brazil. To update these values, we assumed that the percentage of confined cattle in comparison with total bovine herd would be maintained by municipality, thus allowing to extrapolate confinement cattle heads to 2013. Bovine heads not in confinement, for 2013, was estimated by residue. Intensification simulations were done on cattle heads not yet confined, in the following scenarios:

a. Intensification of 10% of unconfined cattle for all LA municipalities for a 10 years' period, with intensification of 1% of total unconfined heard each year during this period

b. Intensification of 20% of unconfined cattle for all LA municipalities for a 10 years' period, with a 2% herd intensification each year during this period

c. Intensification of 30% of unconfined cattle for all LA municipalities for a 10 year´s period, in 10 years, with a 3% herd intensification each year during this period.

Percentages were defined from a literature review, like Barbosa et al. (2015), that projected such information for the Amazon. Soares-Filho et al (2010) state that, ruminants' methane emissions are a function quantity of ingested food and diet quality. Intensified livestock farming emits more methane than traditional livestock as livestock feeds on products that can generate more methane in the rumen by bacterial processes. However, it should be emphasized that feeding intensive livestock reduces the animal's life cycle, reducing the time it takes during fattening, increasing daily weight gain, and increasing its productivity. Cardoso et al. (2016) showed that despite methane emissions reductions in 5 cattle intensification scenarios, nitrous oxide emissions tend to increase in two scenarios (fertilized grass pastures and 5 to 10 years pastures renewal), as a result of manufacture and application of nitrogen fertilizers, using Life Cicle Assesment methodolgy.

5.2.1 Changes in attributes: pastures release

According to a study by Demarchi et al. (2006), the intensification of livestock breeding produces an increase in the efficiency of meat production using technologies, resulting in lower methane / kg ratios of meat produced; And that this better use of the energy of the food can generate a reduction in the individual emission of methane. Therefore, the study estimates that only with the improvement in the nutritional management of animals, it could be possible to reduce slaughter age from 4.5 to 2 years, and then it can reduce methane emission by about 10%. The reduction in the age of slaughter reflects in the reduction of the size of the herd, however with an increase of capital turnover in the sector.

According to Embrapa (2006) for the state of Pará, intensification of livestock production leads to a reduction in the pasture area of 0.84 hectares on average for each intensified animal unit (UA)[32], while there average of 1,35 AU for intensification of 1 hectare (Table 49).

Table 37: Technical parameters for cattle intensification

Parameter	AU*/ha	ha/AU	Head/ha[33]
Mean traditional	0,75	1,33	0,62
Mean intensive	2,1	0,495	1,64
Difference	1,35	-0,84	1,12

Source: own elaboration based on Embrapa (2006). AU= animal unit

The simulation with the three intensification scenarios was done for the two systems of production - traditional/extensive and intensive/confined. Therefore, the difference between initial and final hectares was observed with the two production systems, resulting in the value of pasture areas that would be liberated for other types of activities, such as agricultural production or conservation activities (Table 44).

Table 38: Released pastures hectares from cattle ranching intensification, FU, LA and total Brazil (hectares).

FU	Liberated area 10% int. (ha)	Liberated area 20% int. (ha)	Liberated area 30% int. (ha)
AC	271.608	543.216	814.824
AM	125.506	251.012	376.518
AP	11.369	22.738	34.107
MA	377.653	755.306	1.132.958
MT	1.692.381	3.384.763	5.077.144
PA	1.224.402	2.448.804	3.673.206
RO	1.463.033	2.926.066	4.389.099
RR	53.641	107.283	160.924
TO	406.818	813.636	1.220.454
Total LA	5.626.411	11.252.823	16.879.234
Total BR	12.407.542	24.815.084	37.222.627

Source: Own elaboration.

Previous table shows that liberated areas are more likely to be found in Mato Grosso, Pará and Rondônia. States with less liberated area are Roraima, Amapá, Amazonas and Acre. Total liberated area in Legal Amazon represents 38% of total possible liberated area in Brazil. What

[32] Embrapa (2006) study uses animal units (AU), while the number of bovine heads was being used as measurement unit. Thus, cattle heads are converted to AU using the information IBGE's Census of Agriculture (2006) with the live weights of each animal (calves, steers, cows and bulls, etc.). It is assumed that the proportion of AU per municipality in 2006 will be the same as in 2013.

[33] To transform AU to head/hectare, we took the mean value of 832, 82 kg/head , which is the value of the weight of different classes of cattle for Brazil in 2013.

this means is that intensification process can be developed more intensively in municipalities outside the Legal Amazon.

5.2.2 Changes in attributes: methane emissions reduction

Monteiro (2009) estimated the variation in methane emission for different production systems, which was adapted to calculate the variation. Having said this, one can observe the emission avoided with the intensification of livestock (Table 51).

Table 39: GHG emissions by carcass production for two simulated scenarios

Variable	Traditional	Intensive
Methane produce by a carcass (CH_4kg/kg)	0,78	0,51

Source: adapted from Monteiro (2009)

Thus, the emission of methane can be obtained for both the extensive system and the intensive / confinement system, by multiplying the factors described above and Animal Unit (UA) by municipality (Table 46).

Table 40: methane emissions for three cattle ranching intensification scenarios

Scenario	tCH_4			tCO_2eq		
	10%	**20%**	**30%**	**10%**	**20%**	**30%**
Traditional system (BAU) BR	6.068.751	12.137.503	18.206.254	206.337.545	412.675.091	619.012.636
Traditional system (BAU) LA	2.322.434	4.644.867	6.967.301	78.962.744	157.925.488	236.888.231
Confinement/intensive system (SEM) BR	3.968.030	7.936.059	11.904.089	134.913.010	269.826.021	404.739.031
Confinement/intensive system (SEM) LA	1.518.514	3.037.029	4.555.543	51.629.486	103.258.973	154.888.459
Methane emissions reduction (BAU-SEM) BR	2.100.722	4.201.443	6.302.165	71.424.535	142.849.070	214.273.605
Methane emissions reduction (BAU-SEM) LA	803.919	1.607.839	2.411.758	27.333.257	54.666.515	81.999.772

Source: own elaboration.

Table 46 shows different CH_4 emissions abatement alternatives. Thus, with scenarios of livestock production intensification, it is possible to estimate avoided emission in up to 2,4 million tCH_4 for LA while for Brazil it would be 6,3 million tCH_4, that is, in a scenario of 30%

livestock intensification would result in a 35% reduction of methane emissions from enteric fermentation.

The following tables show distribution of total emissions base line and confinement/intensive system by Federal Unit and biome.

Table 41: Methane emissions for 10% cattle ranching intensification BAU and SEM scenarios, by Federal Unit (tCH_4)

FU	Traditional system (BAU)	Confinement/intensive system (SEM)	Methane emissions reduction
AC	77.027	50.364	26.663
AM	41.674	27.248	14.426
AP	4.636	3.031	1.605
MA	206.901	135.282	71.620
MT	817.430	534.473	282.957
PA	558.796	365.367	193.430
RO	356.170	232.880	123.289
RR	22.379	14.632	7.747
TO	237.421	155.237	82.184
Total LA	**2.322.434**	**1.518.514**	**803.919**

Source: own elaboration.

Table 42: Methane emissions for 10% cattle ranching intensification BAU and SEM scenarios, by biome (tCH_4)

Biome	Traditional system (BAU)	Confinement/intensive system (SEM)	Methane emissions reduction
Amazon	1.704.638.259	1.114.571.169	590.067.090
Cerrado	560.017.781	366.165.472	193.852.309
Pantanal	57.777.601	37.777.662	19.999.939
Total LA	**2.322.433.641**	**1.518.514.304**	**803.919.337**

Source: own elaboration.

Previous tables show that total emissions follow cattle ranching distribution, that municipalities within Mato Grosso, Pará and Rondônia states, present the highest CH_4 emission, and will present highest emissions' reductions. The have a 74% of total emissions in LA.   In addition, municipalities located in Amapá, Roraima and Amazonas states present the lowest emissions, because of lowest quantity of cattle heads. We estimated a 3% share on total LA emissions, for these states. This data shows that there is a concentration on methane emissions in some municipalities within the Legal Amazon.

In terms of biomes, Amazon concentrates 73% of total CH_4 emissions, Cerrado 24% and Pantanal 2%. Amazon emission are almost 3 times the ones calculated for Cerrado. It is important to identify which municipalities within biomes and Federal Units account for the highest emissions.

Livestock intensification information can also be presented relating the avoided methane emission and municipal areas following the order of municipalities with the highest emission reduction per total hectare (Figures 71 and 72). It can be seen that in municipalities with greater livestock production, the change to intensive livestock production leads to a large reduction of methane emissions. The areas to the right of the graph correspond to municipalities with less presence of livestock activity and with less impact of the conversion to intensive livestock. In other words, intensification in a relatively small number of municipalities would have a major impact on the reduction of methane emissions, this happens in Brazil and in Legal Amazon municipalities as well.

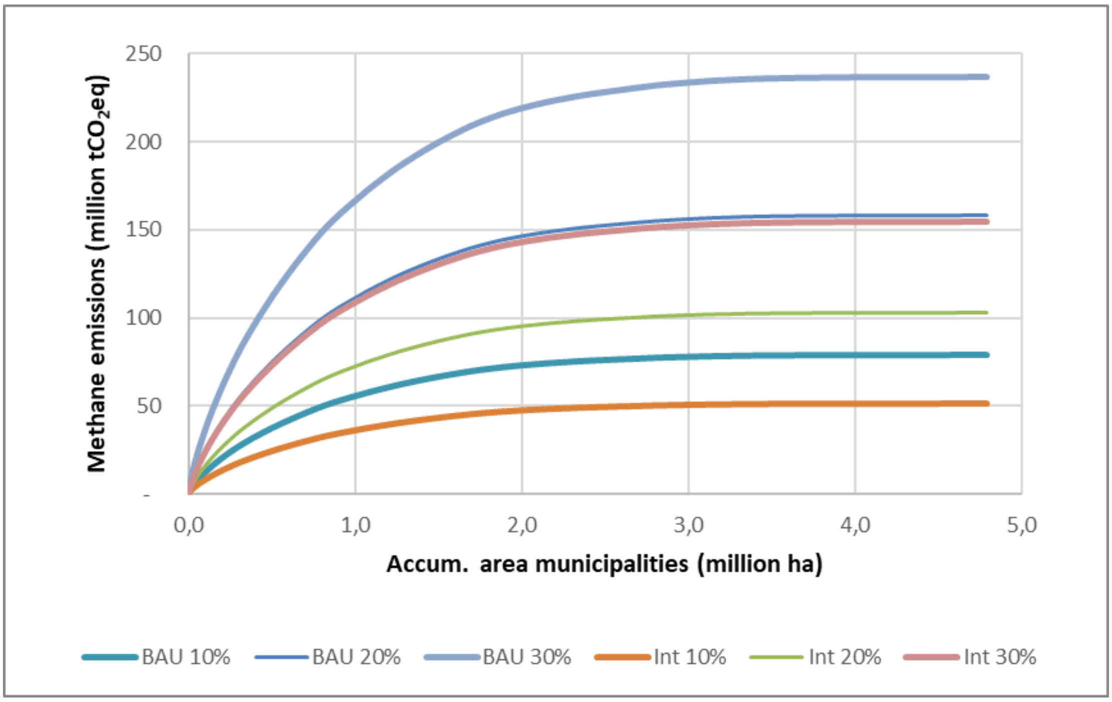


Figure 59: BAU and methane emission's reduction for 3 scenarios (MtCO$_2$eq).

Source: own elaboration.

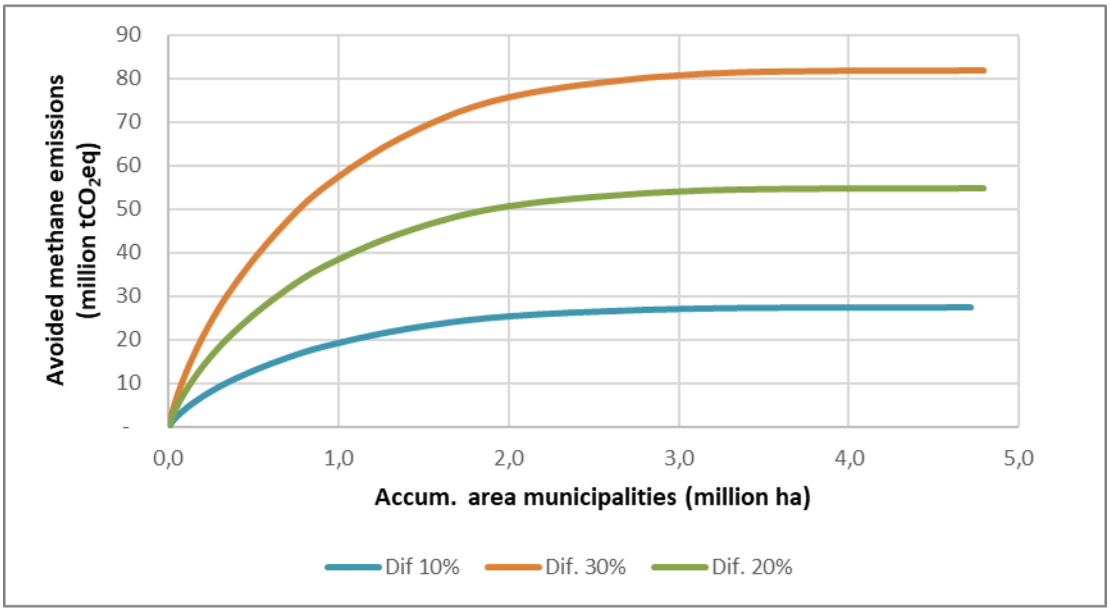
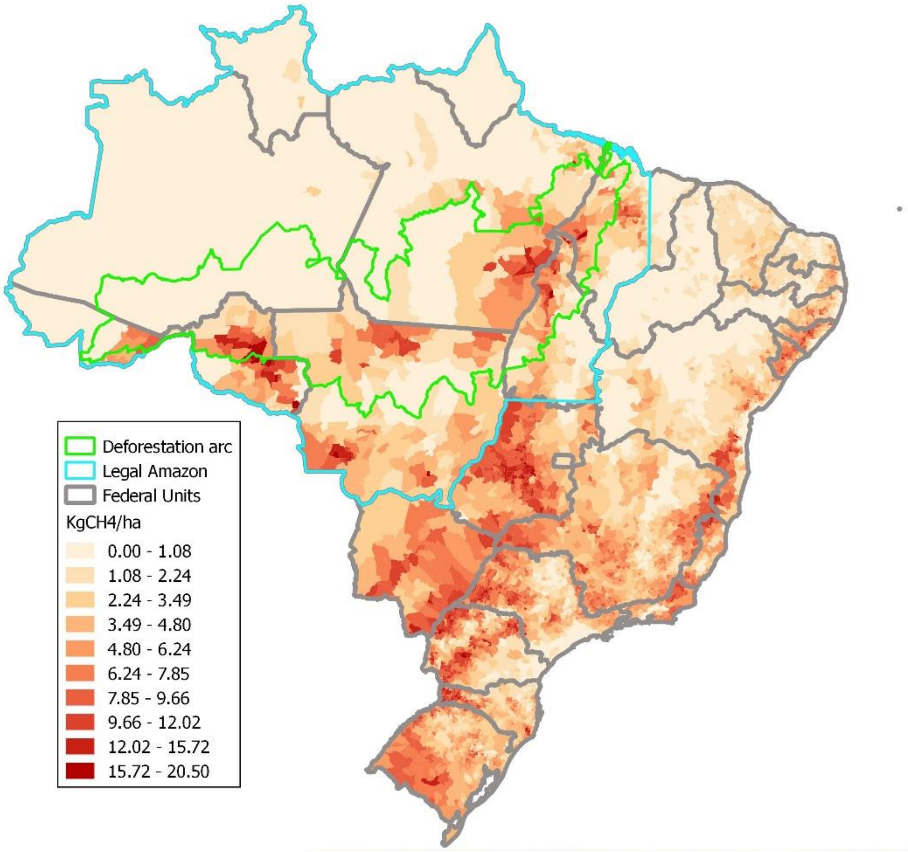


Figure 60: Avoided methane emissions from cattle ranching intensification scenarios for Legal Amazon (MtCO_2eq).

Source: own elaboration.

Previous graphs show that it is possible to prioritize municipalities with the largest herd, proportionally to their area. Therefore, these municipalities should be prioritized in the case of a PES aimed at encouraging the reduction of methane emission from the intensification of livestock since they have the largest herds. It can be exemplified that if 30% of livestock were intensified in the 50 million hectares with the largest herd in Legal Amazon, there would be an emission reduction of 38,3 million tCH_4 (Map 38).



Map 31: Avoided methane by municipality area.

Source: own elaboration

Previous map shows de municipal distribution of avoided methane emissions. It is clear that, municipalities that are located in Mato Grosso, and Pará have the highest ratio between avoided emissions and municipal area. This map shows the intensity of CH_4 emissions reduction. As expected, municipalities located in northern Amazon, northern Pará, and some central Mato Grosso municipalities present the lowest ratios. Other interesting municipalities are located on Maranhão, and northern Tocantins.

5.3 Valuing impacts through economic modelling and PES

Consideration should be given to the cost of intensifying livestock farming. The average costs for maintenance and implementation for intensive livestock/confinement are presented in Table 49, based on Embrapa (2006), and updated to 2016 USD.

Table 43: Cost parameters for intensive cattle ranching establishment and maintenance in Pará state (2016).

Type of system/cost	2016
Traditional cattle ranching mean costs (USD/ha/year)	$ 60,19
Annual maintenance cost for intensive cattle ranching (USD/ha/year)	$ 150,48
Implementation costs for 1 hectare of grass in capoeira grass areas or secondary vegetation (year 0) (USD/ha/year)	$632,85

Source: adapted from Embrapa (2006), with price adjustments to 2016 using GDP implicit price deflator.

Despite high implementation costs presented by Embrapa (2006), this cost is lower than those described in the literature, such as the study of the International Institute of Sustainability (IIS, 2015), which presents the initial cost of USD $750,70 /ha. According to IIS (2015), farms that have been adopting these intensification techniques use a strategy of intensifying pastures from 5% to 20% in Apuí, Amazonas state, (a project developed by the Institute of Conservation and Sustainable Development of Amazonas - Idesam), in Paragominas, Pará (project by the Rural Producers' Union of Paragominas in partnership with Imazon) and in São Félix do Xingu (supported by The Nature Conservancy). From these calculations, it is possible to define an average cost per year to implement and intensify livestock production (Table 73).

Table 44: Mean annual cost for cattle ranching intensification by municipality and total mean costs for LA, bases on intensification scenarios. Million USD.

	10% intensification	20% intensification	30% intensification
Mean annual cost by municipality for 10 years	$ 1,1	$2,3	$ 3,5
Total mean cost, 10 years for LA	$921	$1.843	$ 2.764

Source: own elaboration.

We assumed that implementation costs occur for ten years (2014 to 2023), while the maintenance cost for intensification of livestock production occurs until 2030. Despite the high costs of intensifying livestock production for the three scenarios, adoption of agricultural best practices in livestock farming can generate an increase on income for owners in the medium / long term. Thus, it can be demonstrated that the implementation of such actions can generate gains above the costs of implementation and maintenance. Some studies such as Bedoya et al. (2012) demonstrate economic viability for the Low Carbon Agriculture Program (ABC), with an average yield for extensive and intensive livestock farming of USD $49 /ha/year and USD

$ 232 /ha/year, respectively. However, the information presented in Embrapa (2006), which presents the following income for agricultural activities, is used (Table 50):

Table 45: Net income for different cattle ranching systems (2016 USD).

Cattle ranching system	USD$ /ha/year
Extensive/traditional cattle ranching	$107,90
Intensive/confinement cattle ranching	$487,73

Source: adapted from Embrapa (2006)

The value presented by Embrapa (2006) for the extensive / traditional cattle ranching of USD$ 107,90 /ha/year, is an estimated average yield for all Brazilian livestock. Young (2016) generated an estimate of net income for different production systems based on the methodology for opportunity cost of land, pointed out earlier. For cattle ranching, their result has a median value of USD $58,96 /ha/year. Conservatively, it was decided to use the values presented by Embrapa (2006). Thus, as was done for the intensification of livestock production, it is possible to estimate the average income per municipality per year by increasing calving, at the end of 10 years, by about 10%, 20% or 30%.

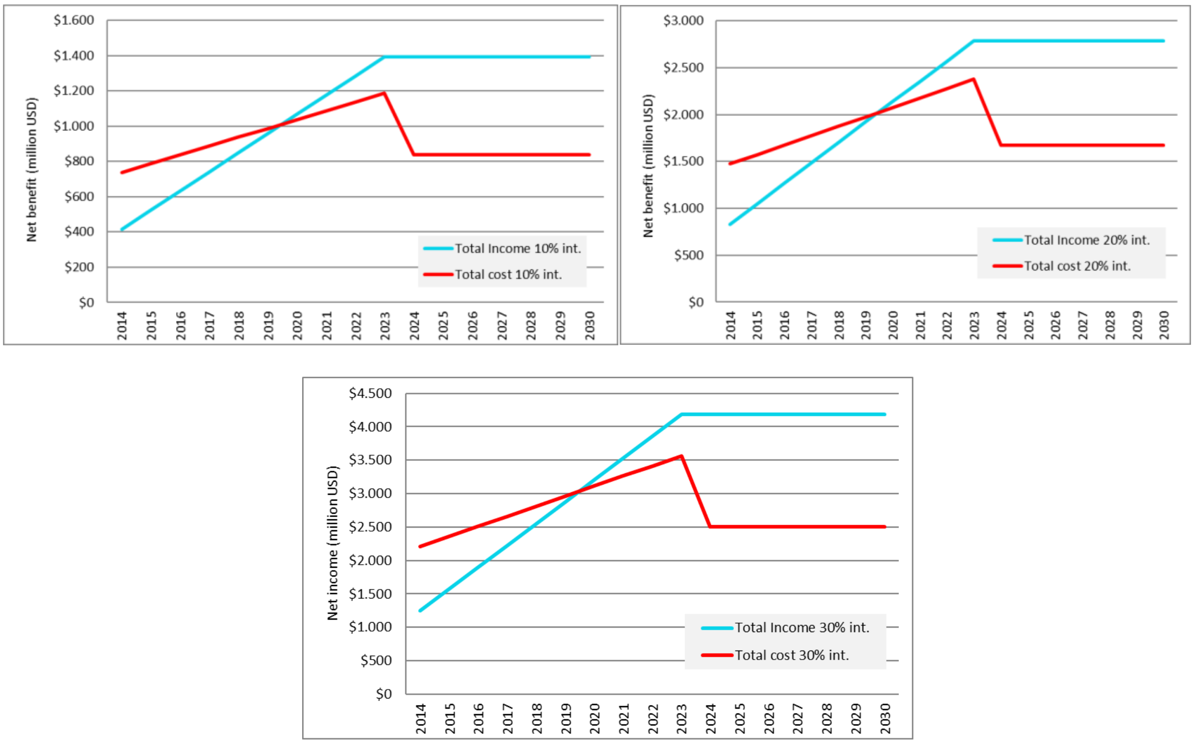
Table 46: Mean annual income from cattle ranching intensification, by municipality, for a 10 years period, and mean annual income for LA (USD).

	10% intensification	20% intensification	30% intensification
Mean annual income, 10 years period, by municipality	$1,4 million	$2,8 million	$4,2 million
Mean annual income, 10 years period for LA.	$1,1 billion	$2,2 billion	$3,3 billion

Source: own elaboration.

When comparing yields and annual costs of intensification of livestock by the 10%, 20% or 30% increase scenarios over 10 years, we observed that, at the end of the intensification process, value of yields is higher than costs (Figure 74).

Figure 61: Annual revenues and costs from a 10%, 20% and 30% cattle ranching intensification for a 10 years period in Legal Amazon.



Source: own elaboration

Last three graphs show income and costs for three different cattle ranching intensification. It is clear that intensification is a profitable activity but not in the short run. Implementation of intensification activities imply that productive system needs adjustments while it reaches an optimum. Previous graphs show that positive returns can be reached after year 6. An interesting opportunity arises for an incentive design, because if the proposed PES covers these net income differences it can help the agricultural producer to make some adjustments in the short and medium run. It is also clear that higher intensification rates, generate higher yields, as presented by IIS (2015).

Erazo (2014b), showed that implementation of sustainable cattle ranching in Orinoco Grasslands in Colombia showed a similar pattern as the one we established for sustainable cattle ranching in LA. This situation is a disincentive for cattle rancher to establish this type of system, so, an incentive that promotes implementation of intensive cattle ranching, must identify how much net income is lost by a cattle ranching, each year and for a how many years. Therefore, our first alternative identifies the following values for net income for all municipalities within LA.

Table 47: Net income for all municipalities within LA, for three different intensification scenarios (2017 USD).

Scenario	2014	2015	2016	2017	2018	2019	2020
Int.10%	-$ 321	-$ 263	-$ 204	-$ 145	-$ 87	-$ 28	$ 30
Int. 20%	-$ 642	-$ 525	-$ 408	-$ 291	-$ 174	-$ 57	$ 60
Int, 30%	-$ 963	-$ 788	-$ 612	-$ 436	-$ 261	-$ 85	$ 91

Source: own elaboration

Previous table shows yearly net income for gradually intensifying cattle herd in LA. For the first 6 years, implementation costs and maintenance costs for alternative cattle ranching surpass productivity gains. It is important to remember that each year 1/10 of total estimated area is intensified until year 10 (2023). Therefore, PES should leave the cattle rancher as better as if the policy has not been implemented, that is, at least with a zero net income (as BAU reference net income). Then, PES costs will be mainly focused on the years that present a negative income. The following table shows total costs of such a PES for a 6 years' period.

Table 48: Total costs and per hectare costs of PES compensating net income loss from sustainable cattle ranching implementation (2017 USD).

Scenario	Total cost (million USD)	liberated area (ha)	Total cost per liberated hectares (USD/ha)	NPV total cost (million USD)	NPV of total cost/ha (USD/ha)
Int.10%	1.048	5.626.411	186	908	161
Int. 20%	2.096	11.252.823	186	1.816	161
Int, 30%	3.145	16.879.234	186	2.724	161

Source: own elaboration

Previous table shows that as intensification areas increases, total PES costs increases, because there are more hectares being implemented and under an incentive scheme. For 10% herd intensification, total costs will be USD $1 billion, with an associated net present cost of USD $908 million. If policy reaches 30% of heard intensification, total costs go up to USD $3,1 billion, with a total net present value of USD $2,7 billion. Mean current value of the incentive, per liberated area is approximately USD $ 186/ha, and in net present value it amounts USD$ 161/ha.

Now, we use a similar methodology to the one used on carbon dioxide emissions reduction from deforestation to determine an implicit emission's price. We used the net present value for the opportunity cost for 17 years, plus implementation and maintenance costs for intensive cattle ranching for the same period. We also used the total amount of CH_4 emissions that would be avoided by municipality, to calculate the implicit price for CH_4 emissions reduction.

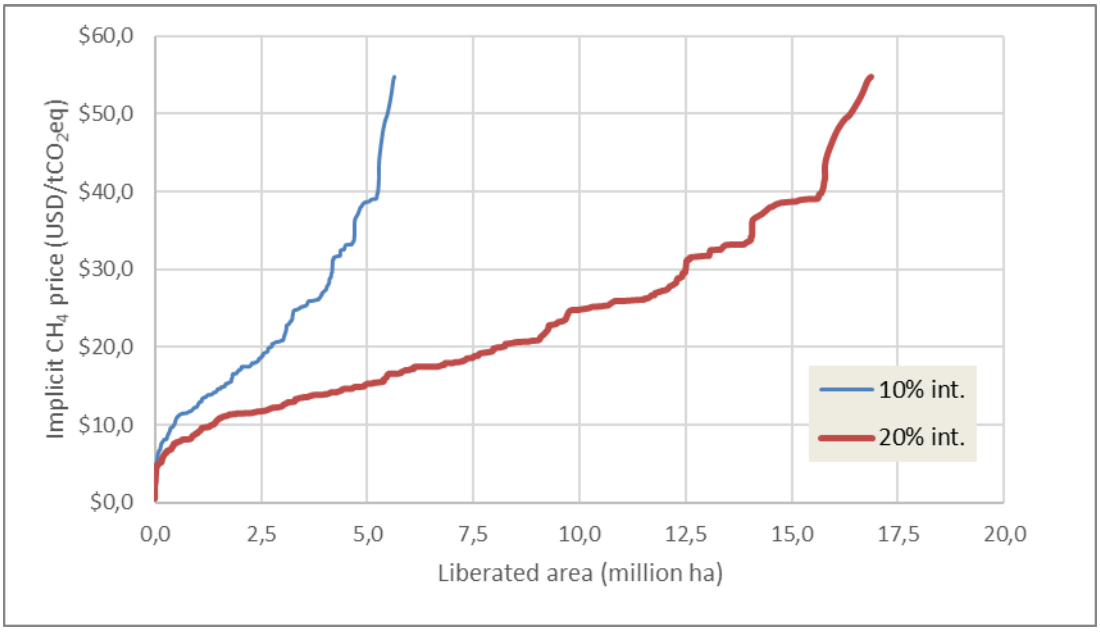


Figure 62: Implicit methane reduction emissions' price for 17 years, and area under PES for 10% and 30% intensification scenario, in LA (USD/tCO₂eq).

Source: own elaboration

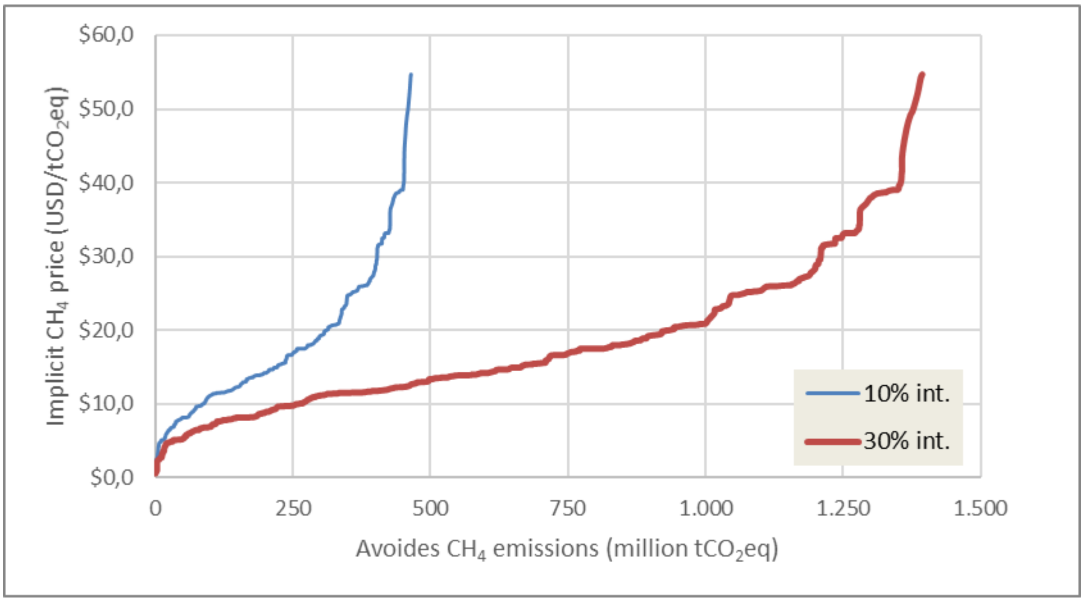


Figure 63: Implicit methane reduction emissions' price for 17 years, accumulative avoided emissions for 10% and intensification scenario, in LA (USD/tCO₂eq).

Source: own elaboration

Previous figures show that, areas at the left are cheaper areas, which reduce higher amounts of CH_4, with an associated low opportunity and implementation costs. Prices for avoided methane vary from nearly a few cents to 54 USD/tCO_2eq. It is somewhat difficult to compare this prices with marked prices reported for short run CER's by Ecosystem Marketplace for livestock methane. For 2014 mean price for this type of project was USD $6,5/t$CO_2$eq and for 2016 it was USD $7/ t$CO_2$eq. We will assume that this price is paid to the livestock producer that implements intensification of cattle during 17 years, and that intensified cattle head will continue to be the same during this period. If this assumption holds, and we assume a 6% discount rate, these yearly prices can be transformed into USD $72,19/t$CO_2$eq and USD 77,7/t$CO_2$eq as total payment, in net present value, for each ton of methane that is avoided during that period. Using any of these prices, it is possible to liberate all the area associated to 10% intensification (5,5 million hectares) and to 30% intensification (16,8 million hectares), with an associated quantity of avoided emissions of 464 and 1.393 MtCO_2eq. An alternative policy would be to take the median of the implicit CH_4 price: USD $11,76 /t$CO_2$eq. With this associated price, a total of 791.000 and 2,3 million hectares would be liberated for each the 10% and 30% intensification scenarios, approximately 14% of total projected liberated area. Associated emissions reduction would be 129 and 388 MtCO_2eq, approximately 28% of total emissions reduction.

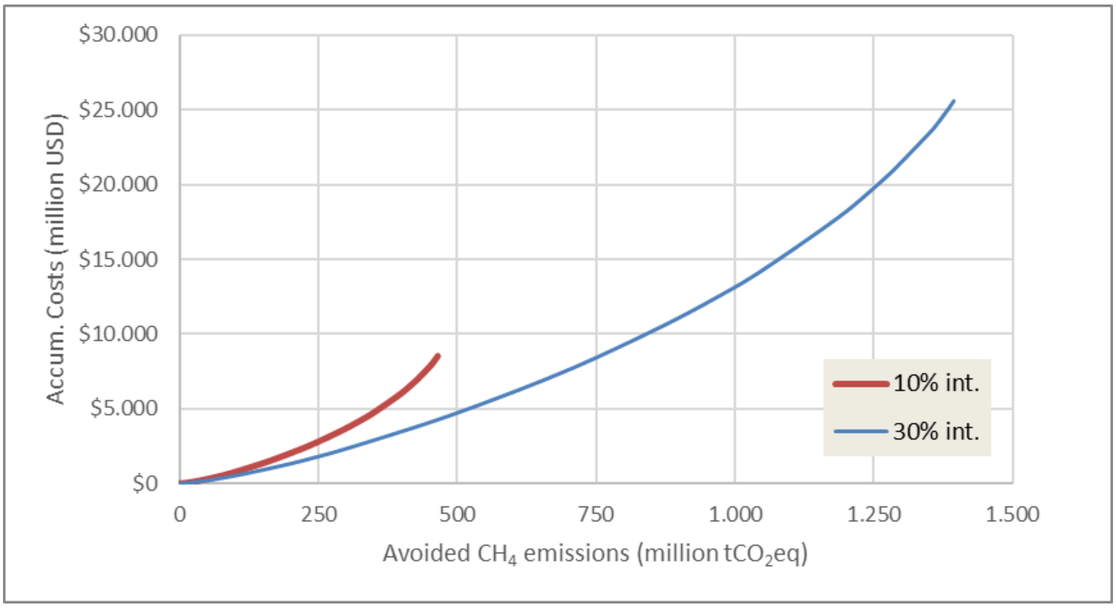


Figure 64: Accumulated costs and accumulated avoided methane emissions

Source: own elaboration

Total accumulated costs using the methane price would be USD $8,5 and USD$ 25,5 billion. If we use the median value of CH_4 implicit price, total costs will be USD $1,1 and USD $3,3 billion, for a 10% and 30% intensification scenarios.

Until now, we have identified total implementation costs, paying for net present value of opportunity costs of land in livestock uses and implementation costs of intensive cattle ranching, as a basis for the PES to promote methane emissions reduction from establishing intensified cattle ranching. We calculated an opportunity cost based on data from Young (2016), for opportunity cost of pastures rental and net benefits of cattle ranching activities for LA municipalities. We made an average of these two indicators in to reflect different land alternatives, which are, direct use or renting it to other livestock producers. We do have an additional option for calculating the PES value: paying just for the change in net income for the cattle rancher, until he reaches an equilibrium point.

5.4 Conclusions

Most of cattle ranching is located in Northern region, because of migration production of cattle activities from center of the country to Legal Amazon area. Then, methane emissions from cattle ranching are also produced mainly in this region, but just for recent years (from 2010). In legal Amazon Mato Grosso, Pará and Rondonia states lead methane emissions, as they share the highest quantity of cattle heads. Anyway, some municipalities outside LA, showing higher CH4 emission.

There is great potential of methane emissions reduction in areas with larger cattle ranching herds, with emphasis on some areas of Cerrado and the Deforestation Arc in the Amazon.

Cattle ranching intensification can generate important land liberation for productive or conservation uses. Between 12, 4 to 37,2 million hectares can be liberated. This intensification showed in turn a possible reduction between 27,3 to 81,9 MtCO_2eq methane emission reduction.

Emission reduction are higher in high emitting states, and show important reductions in Amazon biome, being almost 3 times higher than emission’s reduction in Cerrado biome.

Prioritization of municipalities by cattle intensity (heads per municipality area) seems to be an alternative that leads to cost-effective results in terms of investment on cattle emissions’ reductions.

The proposed PES that promotes methane emission reduction, resulted in an associated cost between USD $921 to USD $2.746 million, for 10% and 30% cattle herd intensification. If using compensation from income loss, per hectare incentive amounts USD $161/ha liberated, in net present value covering a 17 years period, with an associated cost between USD $1,0 to USD $3,1 billion (10% and 30% intensification herd respectively).

Using the implicit price of methane emissions shows a very competitive price when compared to international prices for CER's form methane emissions reduction. Total costs for covering all emissions reduction varies from USD $8,5 to 25,5 billion.

Our approach for cattle ranching intensifying, generates liberated areas for conservation or agricultural production. This proposal lies within the debate of land sparing and land sharing. Renwick (2016) defined land sparing as "the intensification of production to maximise agricultural yield within a fixed area and dedicating other land to biodiversity conservation". And for land sharing, also known as wildlife-friendly farming, he states that "the aim here is to maintain biodiversity with less intensive farmed agricultural landscapes". De la Vega-Leinert and Clausing (2018), state that land sparing "legitimize displacement of local people and their land use to compensate for distant, unsustainable resource use". In contrast, land sharing, promotes spatial integration of conservation in agroecological systems, and has the potential to change extraction technologies. We have shown that cattle ranching in the Amazon has important extensive characteristics (like stocking rates), which are lower than other municipalities in Brazil. Despite this situation, cattle ranching production is focused on internal market and international markets as shown in the dependence analysis, looking at future expansion of cattle ranching in the Legal Amazon. Alternatives for cattle ranching intensification have a wide range of alternatives, starting in simple pastures enhancement to establishment of silvopastoral systems or integrated livestock-agriculture-forest systems (ILAF). Our proposal is focused on areas with high cattle herds, but is must also take into account high deforestation and Legal Reserve deficit. In this way, intensification will not promote displacement of agricultural producer, it tries on the contrary to increase their income by monetize some of the invisible ecosystem services that are being generated through cattle intensification. Instead of a trade-off between producing beef (a provision services) and methane emissions' reduction (regulation service), we see the opportunity of a complementarity between these two services. Our approach the show how externalities can be internalized and generate a win-win solution, following TEEB methodology.

Our results show that this debate should focus more on how changes in biodiversity attributes and biophysical characteristics can be translated into human well-being. In fact, Bennett (2017) state that actual debate on land sparing vs land sharing is related with the different alternatives to guarantee food security, while shrinking agricultures environmental footprint. She also states that the debate over which alternative is best cannot be solved because of little quantification of benefits and drawbacks of each strategy. Then, she proposes changing the focus to identifying possible human well-being improvements and ecosystem services generation. Our argument here is that cattle ranching intensification can serve both objectives, depending on the type of system that will be implemented.

In our cattle ranching intensification model we didn't include biodiversity, but it is possible to cross this information with data on biodiversity from Young (2016), as an additional criteria to prioritize sustainable cattle ranching establishment areas. In fact, there are some international experiences that show that carbon capture, biodiversity conservation, water shead protection and soil erosion reduction can coexist at the same time in sustainable cattle ranching projects, like the one implemented in Colombia since 2010 (Chará et al. 2009).

Recalling some of our results from deforestation section, biological conservation corridors imply the identification of three components. In previous discussion, we identify conservation areas, and connectivity network following Sanderson et al. (2006). However, there is still an important component: compatible land uses and human settlements. We identified sustainable cattle ranching as a desirable category of land use that can generate ES, in particular reduction of emissions form cattle ranching intensification

Diaz-Filho & Ferreira (2008) identified as barriers for adopting ILAF systems in the Amazon region the following: high investments, lack of infrastructure and specialized labor, and system complexity and lack of knowledge on associated benefits. SPS can be complex so their adoption is risky when information and TA are insufficient (Ibrahim et al., 2007; Murgueitio et al., 2006). Calle et al. (2009) as information and knowledge barriers the following: requirement of particular skills among workers, some technical advice was not practical or applicable, SPS contradict farmers' previous knowledge, would have liked more technical assistance. Programs intended to promote the adoption of cattle ranching intensification, SPS or sustainable cattle ranching need to address these obstacles.

Murgueitio et al. (2006) identified that some principles of success in the adoption of agroforestry systems for animal production include: participatory farm planning on systems to be established, integrating farmers knowledge and technical knowledge, interdisciplinary analysis (environment, natural resources, commercialization, local economy), motivation tours and demonstration of specific technologies, and economic analysis comparing current situation with improved alternative implementing SPS.

To achieve freedom of choice and action, the agriculture producer, and for our case, the cattle rancher, and their families must be empower, in order to generate appropriating processes for implementing sustainable livestock alternatives. One of this process is participatory farm planning. Farm planning is a strategy that is based on present knowledge and interrelationships of all farm components, to identify strengths, weaknesses, establish direct possible developments and define possible actions to be taken for each family (FAO 2008). One of the conditions for a successful implementation of sustainable agriculture and cattle ranching activities is farmer involvement.

Figure 65: Participatory farm planning: Farm and landscape today and tomorrow.

Source: Erazo (2011) based on CIPAV (1998).

Previous figure shows theoretical implementation of sustainable cattle ranching like intensification, silvopastoral systems (SPS) and agroforestry systems (AFS) in a farm. The only way to be able to reduce deforestation, as indicated by the white circle and to generate reforestation activities (indicated by blue lines with live fences and riparian forests) is by implementing farm planning that consider all the productive systems that coexist at landscape level, and their ecological, economic and social interrelations. When different components of the farm are optimized (forests, water, soils, infrastructure, community organization, capacity building and communication among inhabitants), there is a clear increase of life quality of families living in a watershed (FAO 2008). If producers participate from the beginning in this process, there is a higher probability that adoption will remain in time. If new profitable, environmentally sound and inclusive production alternatives remain on the long run, also conservation activities remain. Then participatory farm planning is necessary when implementing intensification cattle ranching towards reducing CH4 emissions.

For the Legal Amazon an interesting experience matches our approach: Instituto Centro de Vida (ICV), Novo Campo Program. This program helped establishing EMBRAPAS's Good Agricultural Practices (GAP) in 10 farms in Mato Grosso. One of the activities was to intensify 10% to 15% of pasture area, implement rotational grazing, supplementary feeding, isolation and restoration of degraded Ares of Permanent Preservation (APPs), diagnosis and monthly consultations on property management (Marcuzzo, 2015). The following graph shows ICV's approach.

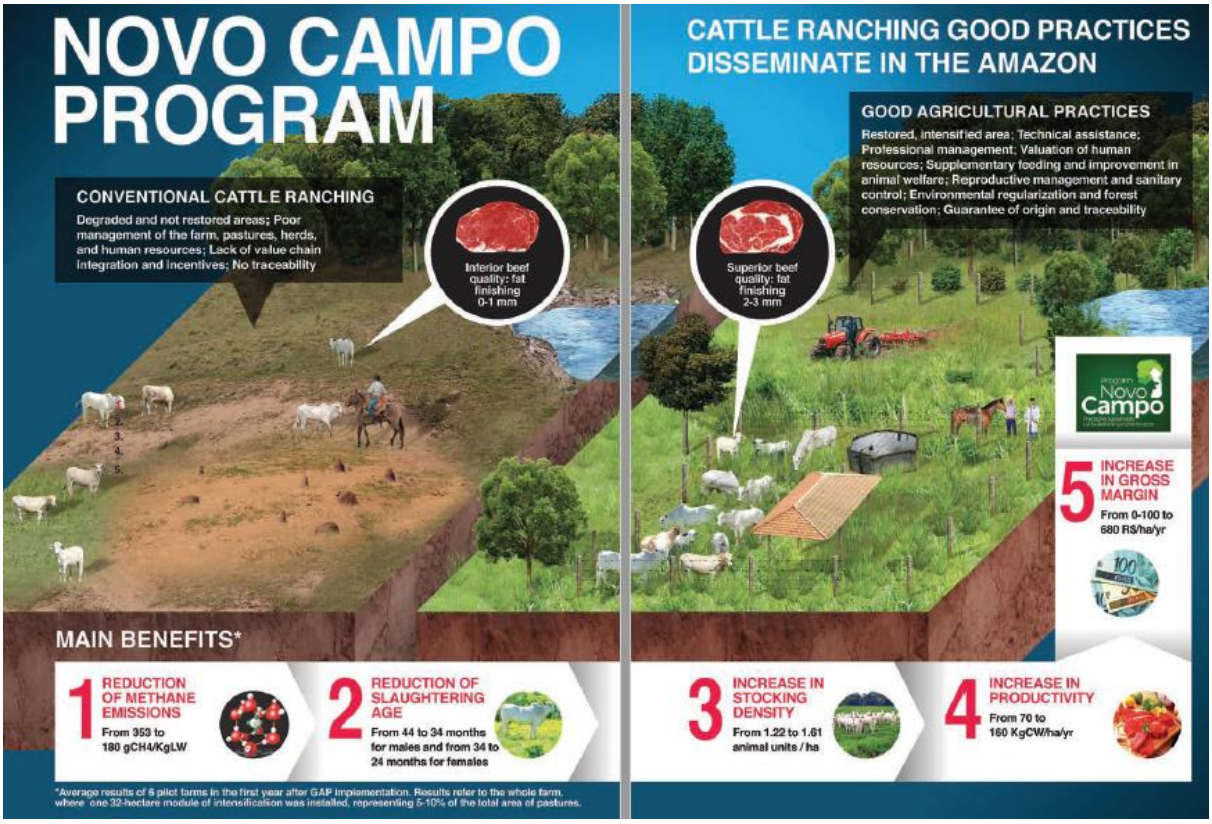


Figure 66: Participatory land planning in Mato Grosso, Novo Campo Program

Source: Marcuzzo (2015)

Previous graph shows that ICV's sustainable cattle ranching program implies land planning form the perspective of the cattle rancher producer. Throughout farm planning, it is possible to identify liberation areas, like riparian forests, cattle confinement, degraded pastures enhancement and supplementary feeding among others.

Finally, connecting farm planning with biological conservation corridors, as described in the previous chapter, is a key issue that can help in harmonizing different planning sacales: in one hand, identification of conservation networks and deforestation risk areas can be done at a landscape level; then, participatory farm planning can complement identification of conservation/sustainable production alternatives at a lower level, but assuring the coordination between activities and results at both levels.

The following maps illustrate this process.

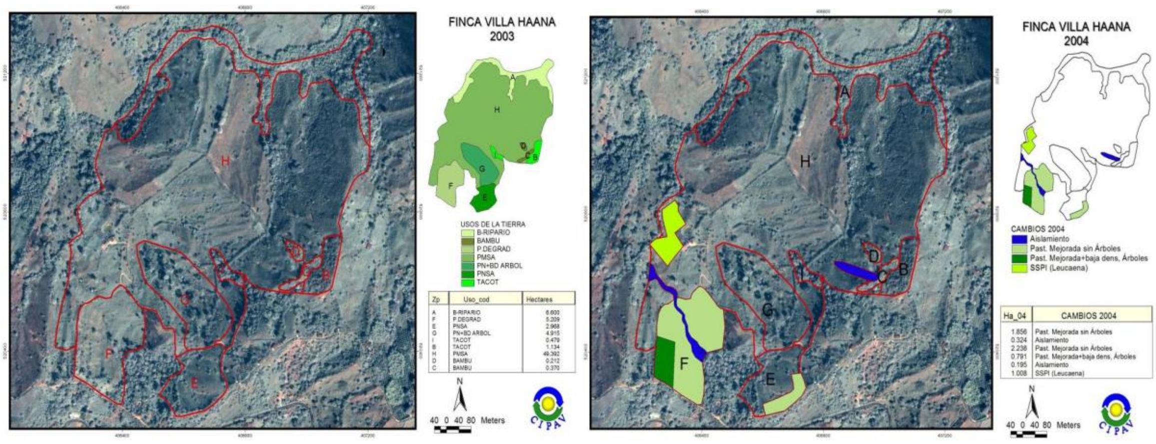


Figure 67: Pastures enhancement, reforestation, and riparian forest protection in a rural property.

Source: CIPAV (2004)

Identification of opportunities at landscape level are complemented with participatoriy farm planning. In the previous figures, identification of intensification areas (silvopastoral systems establishment), fencing areas and pastures enhancement areas are the first step in implementing landscape management tools.

6. BRAZILIAN POLICIES TO REDUCE GHG EMISSIONS

On December 2009, Copenhagen held the 15 Conference of the Parties (COP), from the UNFCCC. Brazil's participation was very important because it declared a voluntary GHG emissions reduction between 36% and 39% compared to a business as usual 2020 scenario. Sectoral reductions were established for Land Use (24%), agriculture and ranching (4,9%-5,1%), energy (6,1%-7,7%) and other sector, mainly charcoal (0,3%-0,4%). Despite of being an ambitus proposal, some environmentalists critique the BAU scenario, because it was built on a 5% to 6% economic growth rate, which is unrealistically high (Francen, 2009).

About 50% of GHG emission's reduction were related to deforestation emissions in the Amazon, and by the end of 2009 it wasn't clear that policy changes were responsible for the drop in deforestation (Francen, 2009).

Proposed government interventions for each sector relate with (Francen, 2009):

- Land use: reduction of deforestation in the Amazon by 80%; reduction of deforestation in the Cerrado by 40%
- Agriculture and ranching: recuperation of pastures, integrated farming and ranching, no-till, biological nitrogen fixation
- Energy: energy efficiency, biofuels, hydropower, alternative sources (e.g. wind)
- Other: substitution of charcoal from deforestation in pig iron production

These commitments were ratified in the National Policy on Climate Change (NPCC), issued in 2009. This Policy along with the Forest Code, that was initially established in 1965 and updated in 2012, are the basis for other policies and programs development in order to achieve the goals set by the Brazilian government.

Table 49: GHG emissions and deforestation strategy public policy framework.

Strategic level	• National Policy on climate Change (2009) • Forest Code (1965 and 2012 modidifications)
Tactical-operational level	• National Climate Change Plan • Action Plan for the Prevention and Control of Deforestation in the Legal Amazon - PPCDAm (2004) • Action Plan for the Prevention and Control of Deforestation and Forest Fires in the Cerrado – PPCerrado (2010), • Low Carbon Emission in Agriculture - ABC Plan (2011) • Agriculture and Livestock Plan (Plano Agrícola e Pecuário - PAP)

Funding	• Amazon Fund • National Climate Change Fund • Amazon and Protected Areas Fund • Resources form PAP: Brazil Bank (Banco do Brasil), and Economic and Social Development National Bank (Banco Nacional de Desenvolvimento Econômico e Social-BNDS)

Source: adapted from MMA (2018)

Table 49 shows a roadmap of policies and programs that are derived from the main two policies, that are at the strategic level, and that help to reduce GHG emission in Brazil. In a tactical-operative level there are some developments like policies to end deforestation in the Legal Amazon and Cerrado biome, that relate with Land Use Change GHG emissions. Low Carbon Emissions in Agriculture plan (ABC plan, by its Portuguese acronym), helps reducing emissions from agriculture and ranching, but form the financing point of view, it is nested within the Agriculture and Livestock Plan (Plano Agrícola e Pecuário - PAP), implemented by the Ministry of Agriculture, Cattle Ranching and Supply (Ministério da Agricultura, Pecuária e Abastecimento – MAPA).

At Funding level, we found different institutions that are implementing some of the policies goals, like Amazon Fund. This fund's activities are organized following PPCDAm structure, to help reduce deforestation in the Legal Amazon.

On the agriculture side, BNDS and Brazil Banc are implementing financing programs established within PAP program, but in particular financing activities that contribute to the ABC plan.

As the presidential decree did not include sectorial reduction goals, but 2020 emission goals, several sectorial plans were developed in order to comply with decree emissions reduction goals. These sectorial plans constitute the tactical operational level of GHG emissions reduction policies. Formulated plans include: Decennial Energy Plan, Low Carbon Emissions for transformation industry, Transport and Urban mobility sectorial plan, Emissions reduction plan for steel industry. Action Plan to Prevent and Control Deforestation in the Legal Amazon (PPCDAm, by its Portuguese acronym) is of interest, and we center our focus in this policy because Legal Amazonia concentrates the largest deforestation activity in the country, as previously analyzed. The other policy we will focus is Low Carbon Agriculture Plan (ABC by its Portuguese acronym). This policy deals with agriculture and cattle ranching sector GG emission reduction commitment, as well as other activities to increase agricultural productivity.

We will start mentioning main characteristics of the National Policy on climate Change, and a description of Forest Code changes introduced during 2012.

6.1 Policies description

6.1.1 Forest Code

In 1934 Brazil passed the first Forest Code, to regulate logging activities that were changing forest to coffee growing areas within the Mata Atlantica biome (XXXXXX). Later in 1965, a new version was enacted, increasing protection of forested areas. Despite this update, only until 1990's there was a strict enforcement, that generated great discontent among rural producers that "wanted to clear-cut and manage their lands without government interference" (Chavari et al. 2015). After almost 10 years

Themes	1965 Forest Code	2012 Forest Code
Legal Reserve	<u>Area</u>: At Amazon (Amazon free for exploration): 80% in forest area; 35% in Cerrado; 20% in other regions and biomes. <u>Calculation</u>: statutory reserves excepts APPs. <u>Registration</u>: Register Office.	<u>Area</u>: At Amazon: 80% in forest area; 35% in Cerrado; 20% in other regions and biomes. <u>Calculation</u>: includes APPs booking. Buildings up to four fiscal modules need not reconstruct the RL. <u>Registration</u>: don't need. Permission economic exploitation of NR with permission of National System of Environmental (Sisnama).
Permamnent Preservarion Areas	<u>Calculation</u>: Protection of native vegetation from riverbanks, lakes and springs, having as parameter the full period. <u>Economic activities</u>: Floodplains, wetlands, forests of slopes, mountain tops, and areas above 1800 meters altitude cannot be exploited for economic activities	<u>Calculation</u>: Protection of native vegetation from riverbanks, lakes and springs, having as parameter the regular water level. <u>Economic activities</u>: Floodplains, wetlands, forests of slopes, mountain tops, and areas above 1800 meters altitude may be used for certain economic activities
Riparian forests (RF)	<u>Width of the river RW</u>: RW<10 m. - 30 meters RF 10 m <RW <50 m - 50 m. RF 50 m < RW < 200 m. - 100 m RF 200 m < RW< 600 m. - 200 m RF RW> 600 m. - 500 m. RF Border of mesa: 100 m. RF <u>Removal of vegetation</u>: Requires authorization from the Federal Executive for the suppression of native vegetation in APP and for situations where the execution of works, plans, activities or projects of public utility or social interest	<u>Width of the river</u>: RW < 10 m. : 30 meters riparian rivers of up to 10 feet wide is required, when consolidated in APP of up to 10 meters wide river area reduces the width of the forest to 15 meters. Between 10 and 50 meters: 50 meters of riparian Between 50 and 200 meters: 100 meters of riparian Between 200 and 600 meters: 200 meters of riparian Bigger than 600 meters: 500 meters of riparian Border of mesa: 100 meters of riparian Removal of vegetation: Allows the removal of vegetation in APPs and consolidated

		activities until 2008, provided by public utility or social interest of low environmental impact, including agroforestry activities, ecotourism and rural tourism. Other activities in PPAs may be permitted by the states through the Environmental Adjustment Program (PRA). The removal of native vegetation springs, dunes and -salt marshes may only be given in case of public utility
Consolidated rural area	Does not include the concept of consolidated area. Recomposition, regeneration and compensation are mandatory	Establishes the concept of consolidated rural areas. Homes up to four fiscal modules need not restore the native vegetation
Amnesty	Penalty three months to one year simple imprisonment and a fine from 1 to 100 times the minimum wage	Exempts landowners from fines and penalties under the law in force for irregular use of protected areas until July 22, 2008.

6.1.2 National Plan On Climate Change – PNMC

The National Plan on Climate Change was established in December 2009, by Law No. 12,187. It defines the legal framework for mitigation and adaptation actions throughout the country. It is the result of different studies and proposals developed by Brazilian scientists and governmental staff, in order to deal with climate change issues. Although it has been proposed that it is independent from global agreements on climate change, we must admit that national policies are closely related with international negotiations agreements. In particular, article 5 states that commitments on the UNFCCC and Kyoto Protocol (KP) are guidelines for the national policy.

In its preamble, the law states that the Plan must be in line with sustainable development, in order to achieve economic growth, poverty eradication and reduction in social imbalances.

Article 12 defines national voluntary commitments, which aim to reduce between 36,1% and 38,95% Brazilian projected 2020 GHG emissions. That is between 1.168 and 1.259 million tons of CO_2 equivalent. In terms of reduction from a baseline year (2005), it commits to a reduction of between 6% and 10%.

Total disaggregation of goals for GHG emission on 2020 were defined by presidential decree Nº 7.390, on December 2010. The following table shows the goals by sector.

Table 50: Sectorial emission variations 2005-2020

Emissions (MtCO2eq)	Land Use	Agriculture and Cattle raising	Energy	Others[1]	Total
Observed 2005	1268	487	362	86	2203

Projection 2020	1404	730	868	234	3236
Variation 2020-2005 (%)	11%	50%	140%	172%	47%

[1] Other industrial processes and waste treatment.

Source: Seroa da Motta et al (2011).

For Land Use Change and Forestry, it was stipulated that a 68% reduction will be attained in the Amazon, 23% in Cerrado and 9% in Mata Atlântica, Caatinga and in Pantanal biomes.

Brazilian government has shown some of the results expected from the implementation of this Plan, as a successful policy implementation case. Main results are summarized in the following table.

Table 51: National Plan On Climate Change main results*

- 80% reduction of annual deforestation indices in Legal Amazon compared to the average between 1996 and 2005 .
- 40% reduction of annual deforestation indices in Cerrado biome compared to the average between 1999 and 2008 .
- Expansion of hydroelectric supply, renewable alternative energy sources (wind power), small hydroelectric and bioelectricity, supply of biofuels, and increased energy efficiency .
- 15 million hectares of degraded pastures recovery.
- Expansion of agrosilvopastoral system on 4 million ha.
- Expansion of direct planting, 8 million ha .
- Expansion of biological nitrogen fixation in 5.5 million ha of crop lands , replacing nitrogen fertilizers use.
- Expansion of planting forests on 3 million ha.
- Expanded use of technologies for animal waste treatment, 4.4 million m^3.
- Increase the use of charcoal in steel factories originating from planted forests and improving carbonization process efficiency.

Source: Ministry of Environment

*PPCDAM e PPCDC are responsible for the first two results. Low Carbon Agriculture (ABC) program is responsible for last results.

6.1.3 Low Carbon Agriculture Plan – ABC Plan

Rio+ 20 was a meeting held in 2012, in Rio de Janeiro. Its flagship was the green economy. It stated a new paradigm on the global economic model to be followed. But how can we understand green economy? Is it an economy low in use of inputs that require carbon emissions? In a global study made by Mackenzie & Company in 2009, they explored the opportunities to reduce GHG emissions by identifying available technologies and associated abatement costs. Finally, they found that 200 initiatives, in 10 economic activities have the potential to reduce 55% of GHG emissions with a cost lower than €60/tCO_2. In the study for Brazil, Mackenzie & Company (2009) found that reduction of deforestation and emissions from agriculture and cattle ranching sector were the best abatement opportunities, allowing 85% reduction. But not only deforestation, but also reforestation has a great potential in Brazil, as a result of the amount of degraded and unproductive lands, making of this activity a huge business opportunity in the future.

In 2010, Carbon Finance-Assist Program (CFAP) and Energy Sector Management Assistance Program (ESMAP), developed a similar study for Brazil, in order to identify GHG mitigation potentials. CFAP and ESMAP (2010) found that land use change, land use, forestation and deforestation (LULUCF/D) activities have a huge potential to generate abatement activities. According to the study, agriculture and cattle ranching are responsible for 25% of Brazil´s gross emissions. Some of the technologies available to reduce emissions are direct planting, enhanced forages and genetic improvement in cattle ranching, native forest restoration and reforestation to be used by the pig iron industry. Finally, deforestation control must deal with the increase in demand for lands to be used in agriculture and cattle ranching activities. This can be done through recovery of degraded lands, increasing cattle ranching productivity, increasing the use of silvopastoral systems, promoting feedlots for cattle fattening and protecting forests from illegal use. Following this recommendations, LUCLUF/D will generate 331 tCO_2, in 2030, instead of a 2008 baseline scenario 816 tCO_2.

The Brazilian government is aware of the role that the agriculture and cattle ranching sector has as a potential source of GHG, as a sink source, but also the importance as a key economic growth driver. The commitments established in the Low Carbon Agriculture Plan are the result of the proposal presented by the Brazilian government to reduce its GHG emissions in COP 15, in Denmark, 2009. These commitments for the agriculture sector are also in Brazil’s National Plan on Climate Change. The goals established, follow the shared but differentiated responsibility approach, that is, although the government understands the urgent need of GHG emission reduction, it also recognizes the importance of this sector in terms of sustainable economic growth as well as the impact on poverty reduction, making both objectives compatible (CSPR-MAPA-MDA, 2012).

As shown in table 50, agriculture (including cattle ranching activities) has been increasing its share in the national GHG inventory since 1990, and in 2010, it was reported as the first source of GHG, above industry. As a result, the government generated a series of goals for the sector, to be accomplished by 2020. The goals can be seen in the following table.

Table 52: National Appropriate Actions for GHG emissions reductions proposed by Brazil in Copenhagen Cop 15, 2009.

Nationally Appropriate Mitigation Actions	Range of Estimated Reduction in 2020 (Mt CO2e)	
Reduction in Amazon deforestation	564	564
Reduction in "Cerrado" deforestation	104	104
Restoration of grazing land	83	104
Integrated crop-livestock system	18	22
No-till farming	16	20
Biological nitrogen fixation	16	20
Energy efficiency	12	15
Increase in the use of biofuels	48	60
Increase in energy supply by hydroelectric power plants	79	99
Alternative energy souces	26	33
Iron and steel – charcoal from reforestation	8	10

Source: Carvalho and de Oliveira (2012).

The agriculture sector, corresponding to the second block in the table, must reduce between 133 and 166 million tCO_2e, which represents 43% of national efforts to reduce GHG emissions. This reduction increases when including Legal Amazon and Cerrado deforestation goals, representing 668 million tCO_2e.

The mitigation strategy is focused on the following activities

a) Restoration of degraded pastures: adequate management and fertilization; 15 million (ha) of pasture; reduction between 83 to 104 million tCO_2e.

b) Agrosilvopastoral systems (iLPF): increase implementation on 4 million hectares; reducing 18 to 22 million tCO_2e.

c) No-till farming, or direct planting system (SPD): SPD expand use in 8 million hectares; reduce 16 to 20 million tCO_2e.

d) Biological Nitrogen Fixation- BNF: established on 5.5 million hectares: reductions between 16 and 20 million tCO_2e.

e) Reforestation (production of fibers, wood and cellulose): increase 3 million hectares (from 6 to 9 million hectares).

f) Widening treatment technologies of animal waste (4.4 million m^3) for power generation and organic fertilizers generation.

These activities are planned to generate a GHG emission reduction between 133,9 and 162,9 million tCO_2eq.

The estimated cost of this program is R$197 billion (approximately USD$85 billion). From this amount, R$157 billion (approximately 79% of total budget) will be transferred to final users in the form of subsidized credit. Main activities that will be financed are: technical assistance, training, monitoring and evaluation, implementation costs for proposed technologies adoption, management plan formulation, mapping and most suitable areas identification. Finally, there is an important link with Clean Development Mechanism (CDM) projects, because it increases profitability of proposed projects. In particular, CDM projects were identified as being more suitable for reforestation and animal waste treatment, but until 2016, Brazilian approved projects focused on they were never used as an .

ABC program generated different tools that can be used by farmers and cattle ranchers to implement the identified new technologies that have the potential to reduce GHG emission in the agriculture sector.

From a financial point of view, ABC plan is nested within Agriculture and Livestock Plan (Plano Agrícola e Pecuário - PAP), that is implemented by the Ministry of Agriculture, Cattle Ranching and Supply (Ministério da Agricultura, Pecuária e Abastecimento – MAPA). The objective of PAP is to “contribute more effectively to ensuring necessary conditions to rural producers to expand its activities and increase its competitiveness, with greater insertion in the international market” (MAPA-SPA, 2016b). To reach this goal, PAP is made up of loans that cover rural credit, production and commercialization costs. For the period 2016/2017, a total of R$183,8 billion were assigned to be granted between investment (R$ 38,2 billion and 20,7% share) and production and commercialization costs (R$ 149,5 billion and 79,3% share). ABC program is located within investment resources, accounting for R$ 2,9 billion, with a share of 8,7% of total investment resources and 1,8% of total PAP resources.

Loans are granted through government banks like Brazil Bank (Banco do Brasil), and Economic and Social Development National Bank (Banco Nacional de Desenvolvimento Econômico e Social). Loan conditions are the following:

a) Activities to be financed are: recovery of degraded areas and pastures, the implementation and expansion of crop-livestock-forest integration systems, soil correction and fertilization, conservation practices of soils, implantation and maintenance of commercial forests, implementation of organic agriculture, restoration of permanent preservation areas (Áreas de preservação Permanente – APP) or legal reserve (Reserva Legal – RL) and other practices that involve sustainable production and culminate in low emissions of greenhouse gases.

b) Effective annual interest rates: 8,5% and 8,0% to producer that are associated to the PRONAMP program[34].

c) Financing limits: R$ 2,2 million or R$ 3 million for forest planting, for rural producers with at least 15 fiscal modules' area, and R$ 5 million for producers that own more than 15 fiscal modules' area[35]

d) Maximum repayment term: 15 years, with a no-payment period that varies between 1 and 8 years.

Comparing these conditions to other programs within the investment line of PAP, we can conclude that ACB program has very good conditions in terms of maximum repayment term, and effective annual interest rates. In terms of the amounts assigned per producer, there are other programs that have higher values like PROCAP-AGRO[36] ($R 55 to 65 million) and PRODECOP[37] ($R 110 million), but with shorter repayment term or higher interest rates.

The following table shows use of ABC program resources within different subprogram between 2013 and 2017.

[34] PRONAP program refers to the National Program to Support Mean Rural Producer. In this program includes rural producers with up to R$1,76 million of gross income and at least 80% of its income is generated from agriculture, cattle ranching or vegetation extraction activities (MAP-SPA, 2016b)

[35] Fiscal module is a unit of measure, in hectares, whose value is set by INCRA for each municipality taking into account: (a) the type of predominant exploration in the municipality (horticulture and fruit farm, permanent culture, temporary culture, livestock or forestry); (b) the income obtained in the predominant type of holding; (c) other holdings existing in the municipality which, although not predominant, are expressive according to the income or area used; (d) the concept of "family ownership". The size of a fiscal module varies according to the municipality where the property is located. The value of the fiscal module in Brazil ranges from 5 to 110 hectares. Source: https://www.embrapa.br/en/codigo-florestal/area-de-reserva-legal-arl/modulo-fiscal

[36] Capitalization Program for Agricultural Cooperatives

[37] The Cooperative Development Program for Value Added to Agriculture Production encompasses all cooperative production sectors.

Table 53: ABC program credit funding by subprogram, region and Legal Amazon states, 2013-2017. Millions of reais.

Subprogram	Region						LA states	non LA states
	Center-west	Northeast	North	Southeast	South	Total		
Adequacy and / or env. reg.	$0,65	$0,86	$1,35	$7,90	$17,89	$28,65	$1,59	$27,06
Amazon biomes	$0,00	$0,00	$0,00	$0,00	$0,08	$0,08	$0,00	$0,08
Financing constitutional funds	$25,43	$2,00	$92,95	$0,00	$0,00	$120,38	$105,31	$15,07
Biological nitrogen fixation	$2,00	$0,00	$0,00	$0,00	$0,00	$2,00	$0,00	$2,00
Forests	$23,61	$28,73	$40,21	$86,19	$49,56	$228,30	$47,64	$180,66
CLF* integration and AFS	$83,28	$3,18	$36,32	$13,75	$76,56	$213,08	$69,94	$143,14
No-till farming	$228,22	$262,90	$99,43	$379,70	$148,34	$1.118,59	$254,79	$863,80
Degraded pastures recovery	$820,82	$182,39	$477,09	$402,82	$157,65	$2.040,77	$785,09	$1.255,69
No program associated	$2.597,00	$677,41	$730,52	$2.501,92	$822,45	$7.329,29	$1.588,99	$5.740,30
Organic systems	$2,00	$0,34	$0,00	$0,48	$0,00	$2,83	$0,00	$2,83
Waste treatment	$1,40	$0,00	$1,13	$12,11	$10,72	$25,36	$1,33	$24,03
Total	$3.784,41	$1.157,80	$1.479,01	$3.404,87	$1.283,26	$11.109,34	$2.854,68	$8.254,65

Source: Brazil's Central Bank. CLF= Crops, livestock, forest, AF= Agroforestry systems

Table 53 shows that most of the ABC program resources are not associated with any subprogram, which is 66% form total 2013-2017 available resources. This is an important issue because the use of these resources cannot be associated with a specific emissions reduction goal. Center-west and Southeast regions received R$ 7,1 billion, with a share of 65% from total resources. Main subprograms for these regions are Degraded pastures recovery and No-till farming accounting for nearly 25% of total resources. For Legal Amazon states, there was a total of R$ 2,8 billion (25% of total ABC program resources). Main subprograms were No-till farming and Degraded pastures recovery (approximately R$ 1 billion). We can also see that biological nitrogen fixation and organic systems did not receive funding in Legal Amazon states, while, forests and agroforestry systems received only 1% (R$ 177 million) of total L.A. available funding.

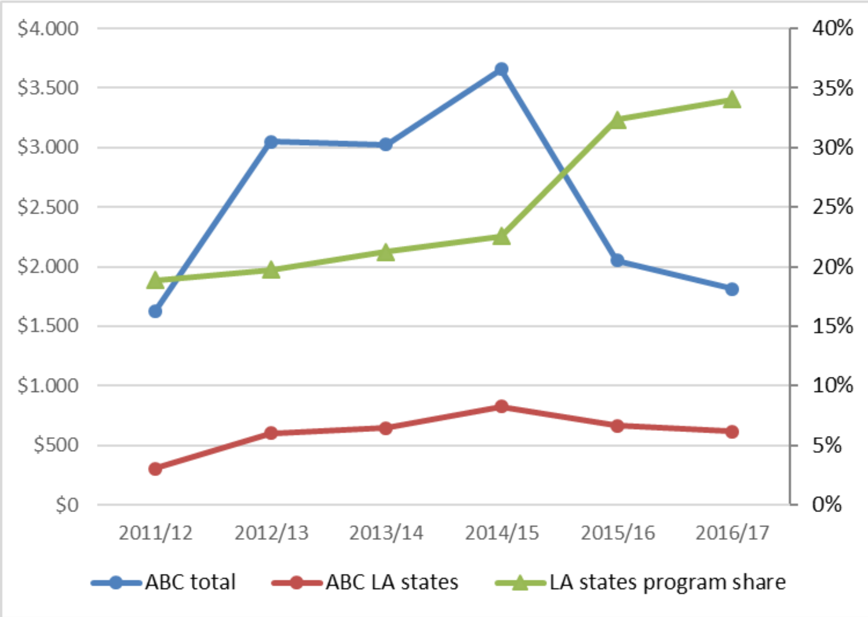


Figure 68: ABC total funds 2011/12 to 2016/17 harvest year. Millions of reais.

Source: based on Observatorio ABC data (2017)

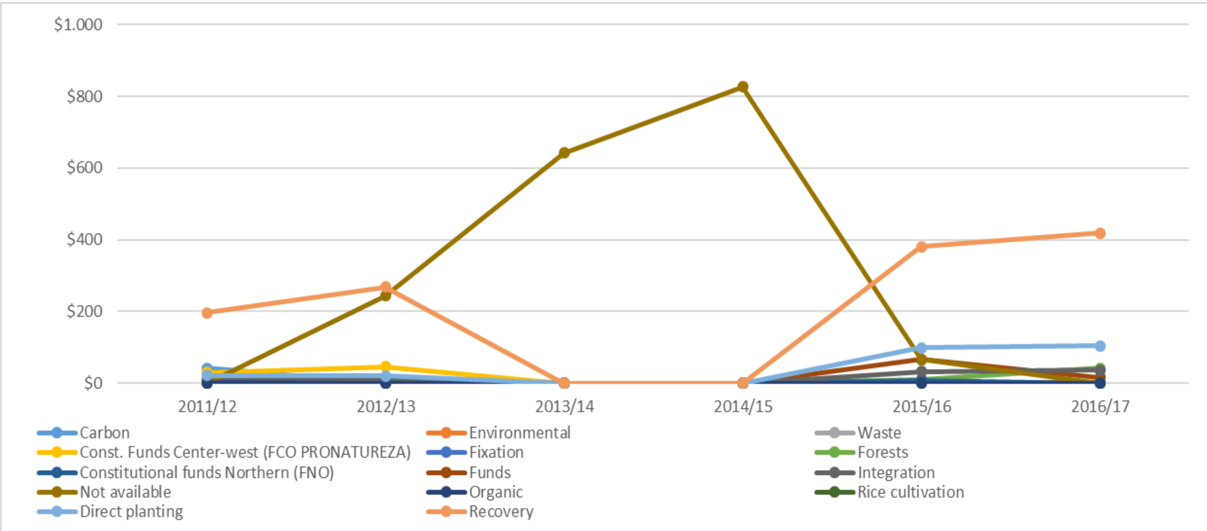
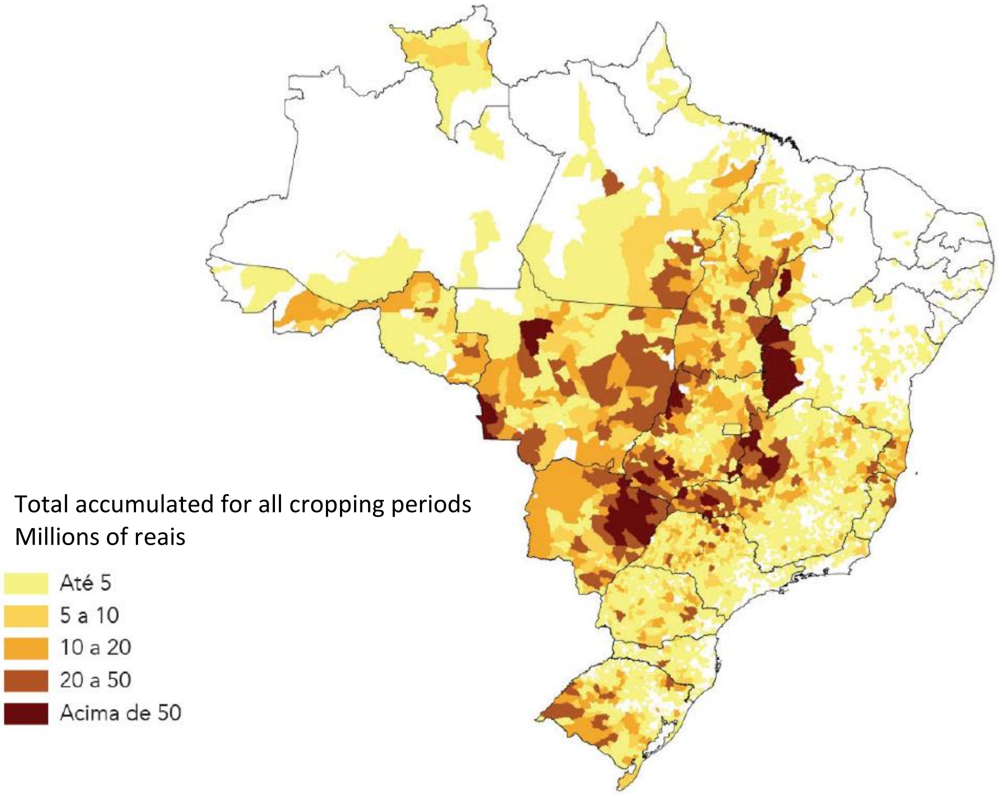


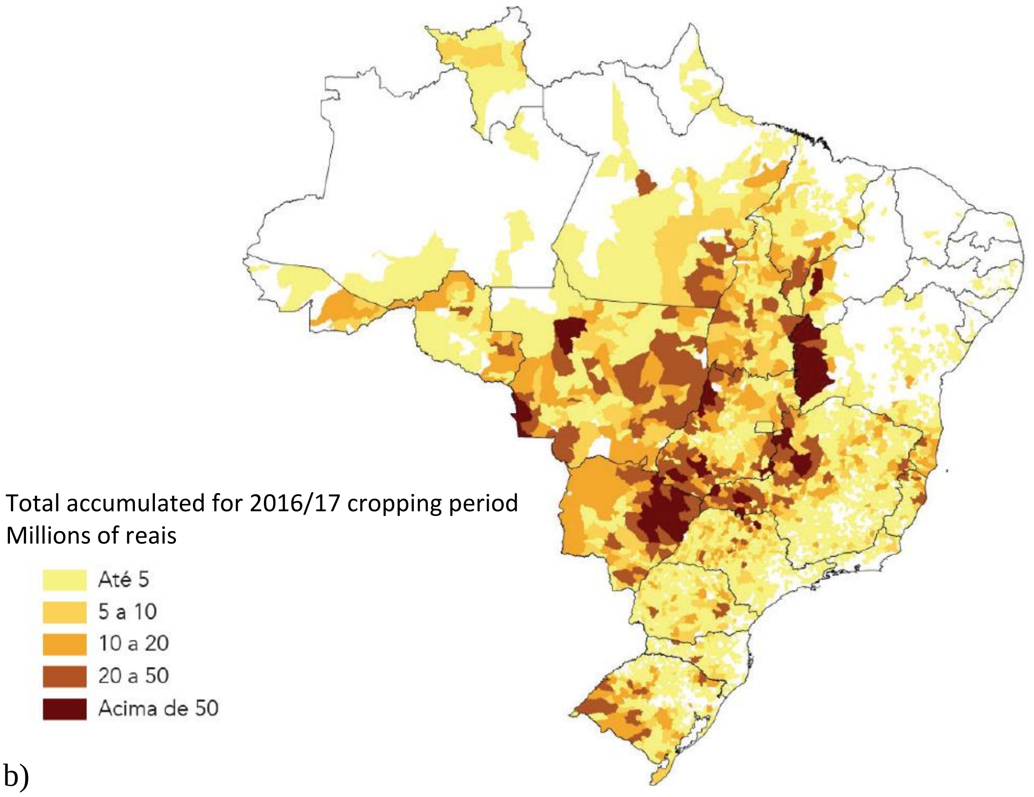
Figure 69: Distribution of funding resources among ABC subprojects, between 2011/12 and 2016/17 cropping periods in Legal Amazon states. Millions of reais.

Source: based on Observatorio ABC data (2017).

When analyzing resources invested in Legal Amazon states (Figure 68), by different ABC subprograms (Figure 69), it is clear that pastures recovery and direct planting received most of funding resources within the las two cropping periods (approximately 72% and 85% share of total resources for each period). Other sub programs like crop-livestock-forest integration and forests, received very few resources, accounting for nearly 5,3% share for the first subprogram and 4,2% share for the second subprogram. In addition, Observatorio ABC (2017) recognizes that there are some other activities that are being incorporated by the financing plan, like oilpalm plantations, organic production, rice cultivation, among others, that are of interest from the fovernment point of view, but they were not included in the initial ABC recognized techniques, and it is necessary to prove that every financed technique is demonstrably associated with GHG emission reduction.



a)



b)

Map 32: Spatial distribution of ABC program resources: a) total expenditure accumulated between cropping periods 2011/12 to 2016/17; b) expenditure for cropping period 2016/17

Source: Observatorio ABC data (2017).

We can also analyze total ABC program funding with total rural credit, in the period 2013-2017. Total Brazilian government rural credit programs, can be seen in the following table.

Table 54: Agricultural credits in Brazil, by program, region and Legal Amazon states 2013-2017. Million reais.

	Region						L.A.	non-L.A.
Program	Center-west	Northeast	North	Southeast	South	Total	states	states
ABC	$3.784	$1.158	$1.479	$3.405	$1.283	$11.109	$2.855	$8.255
FNO-ABC	$0	$0	$100	$0	$0	$100	$100	$0
FUNCAFÉ	$59	$242	$9	$11.370	$576	$12.256	$18	$12.239
INOVAGRO	$265	$142	$46	$1.065	$2.401	$3.919	$118	$3.801
LINHA DE CRÉDITO RUR	$0	$1	$0	$0	$0	$1	$0	$1
MODERAGRO	$569	$88	$42	$483	$1.530	$2.711	$485	$2.226
MODERFROTA	$6.745	$1.218	$748	$4.117	$5.901	$18.729	$5.151	$13.578
MODERINFRA	$413	$174	$23	$763	$849	$2.222	$247	$1.975
OUTRAS LINHAS DE CRÉ	$1	$0	$0	$0	$0	$1	$1	$0
PCA	$2.346	$372	$214	$1.178	$3.033	$7.142	$1.529	$5.613
PRI	$341	$95	$41	$621	$751	$1.849	$172	$1.677
PROAQÜICULTURA	$26	$0	$0	$3	$0	$29	$15	$15
PROCAP-AGRO	$578	$79	$48	$2.244	$5.332	$8.281	$152	$8.130
PRODECER III	$0	$0	$0	$0	$0	$0	$0	$0
PRODECOOP	$274	$0	$150	$277	$4.310	$5.011	$174	$4.837
PROGRAMA NACIONAL DE...	$46	$38	$28	$52	$120	$285	$31	$254
PRONAF	$8.020	$15.249	$8.065	$21.489	$57.769	$110.592	$14.239	$96.354
PRONAMP	$15.777	$4.947	$5.316	$23.791	$38.395	$88.227	$9.971	$78.255
PRORENOVA-INDUSTRIAL	$73	$0	$0	$123	$48	$244	$0	$244
PRORENOVA-RURAL	$14	$22	$0	$646	$321	$1.004	$0	$1.004
PSI-RURAL	$6.319	$1.547	$915	$4.503	$7.925	$21.209	$4.847	$16.362
SEM PROGRAMA	$132.338	$36.413	$18.554	$133.902	$163.052	$484.259	$75.767	$408.493
TOTAL	$177.988	$61.787	$35.778	$210.033	$293.597	$779.182	$115.871	$663.312

Source: Banco Central do Brasil.

Total rural credit between 2013 and 2017 amount $R 779 billion, that is nearly R$ 155 billion per year. From all these available resources, only R$115 billion was going to Legal Amazon states, that is nearly 15% of total period funding. Previous table shows that most of funding was going to South and Southeast regions, with higher resources corresponding to PRONAF, PRONAMP, and PSI-Rural programs. The first program, PRONAF, finances individual or collective projects, which generate income for family farmers and beneficiaries of agrarian reform, has the lowest interest rates on rural finance. It is implemented by financial institutions. The second program, PRONAM, corresponds to the National Program of Support to the Medium Rural Producer, and finances rural producers with annual gross income of up to R $ 1.76 million, if at least 80% of this income originates from the agricultural or vegetal extractive activity. The third program corresponds to the Rural Investment Support Program, finances the acquisition of new agricultural machinery and equipment, manufactured in the country and accredited by BNDES, including tractors, harvesters and agricultural implements and also the acquisition of new trucks, only for rural producers - individuals, residents and domiciled in Brazil, provided that the investment is destined to the agricultural sector[38].

For Legal Amazon states, most important funding comes from PRONAF, PRONAM and MODERFROTA programs. These three programs represent nearly 25% of total funding for 2013-2017 period. MODERFROTA program corresponds to the Agricultural Tractor Fleet Modernization and Associated Implements and Harvesters Program, and finances tractors, harvesters, associated implements, self-propelled sprays and equipment for the preparation, drying and processing of coffee, as well as used items. When we analyze ABC program in total rural funding context, we can see that it has a share of 1,4% of total funding. For the Amazon States, this program has a 2,4% share of total Legal Amazon funding.

We can conclude that ABC program is not as extensive as other rural credit programs. It has a low share in the period 2013-2017, and will continue with low a low share for the 2016-2017 PAP programs. Most of ABC funding is going to other states different from LA states. When analyzing ABC subprograms, we conclude that there is a lack of investment on activities that can help with CO_2 emissions capture, like forestry, agroforestry or crop-livestock-forests integration systems. Investment associated with methane emissions reduction is more evident, associated with degraded pastures recovery and waste treatment. For degraded pastures recovery to be effective, there is a need to intensify livestock production, as seen in previous chapter. This in turn will imply the use of technical assistance, and investments from other programs form the PAP program.

[38] For more information see:
http://www.bb.com.br/portalbb/page103,8682,8690,1,0,1,6.bb?codigoNoticia=19047&codigoMenu=4855

In order to use other crediting programs from PAP program one must take into account that even though, rural credit is an important source for funding agricultural activities in Brazil, policies that increase availability of credit financial resources may potentially promote high deforestation rates (Assunção et al., 2013). Most of Legal Amazon rural funding continues to have high subsidies, that don´t take into account properties' environmental compliance and loan taker environmental laws compliance (MMA, 2016). Government has generated since 2008 credit conditions for agricultural credit granting within the Legal Amazon (CMN/Bacen n° 3.545/2008 resolution), but, there are few studies showing credit restrictions impact on deforestation. On one hand, Costa et al. (2011), analyzed deforestation and credits (in particular, Regional Sustainable Development - DRS, a negotiating strategy administrated by Banco do Brasil). in the Legal Amazon municipalities, and Arco Verde municipalities[39], between 2008 to 2010 years. Their conclusions show that ten municipalities with highest deforestation records only two registered 500 or more credit users, with an associated investment higher than R$ 10.000.000. Investments were mainly associated to livestock for milk or meat production, as well as cassava. As a result, there is no evidence to answer the question if there is a relationship between credits and deforestation. On the other hand, Assunção et al. (2013), analyzed contract-level microdata set compiled by the Central Bank from Common Registry of Rural Operations (Registro Comum de Operações Rurais, Recor) data for 2002-2011 period, and municipal deforestation rates from PRODES/INPE for the same period. Their results show that conditional rural credit can be an effective policy instrument to combat deforestation: 2008 credit constraining resolution generated a decrease in rural credit, particularly for cattle ranching, and this credit reduction is associated with deforestation reductions, especially in municipalities where cattle ranching is the main economic activity.

MMA (2016) state in their Action Plan for PPCDAm, for the 2016-2020 periods that "with the goals of reducing deforestation in perspective, there is scope for mapping and analyzing perverse subsidies to be redirected or even extinguished". Despite this last fact, they recognize that "however, negative conditionalities are not sufficient for an efficient strategy to combat deforestation and should have as counterpart positive incentives that boost the activity of use with forest conservation".

[39] Arco Verde region is composed of the municipalities yearly officially stated as having the highest deforestation rates according to the brazilian government´s Deforestation´s Monitoring Program - PRODES.

6.1.4 Action Plan to Prevent and Control Deforestation in the Legal Amazon (PPCDAm)

Deforestation in the Brazilian Amazon was increasing between 1998 and 2004, according using PRODES data. Figure 70 shows how deforestation was going up to 2005. Total cleared forest area was positive and growing until 2004, with a reduction in 2005. According to governmental data, in 2004, 16% of the Legal Amazon was already deforested, accounting for 670.000 km^2.

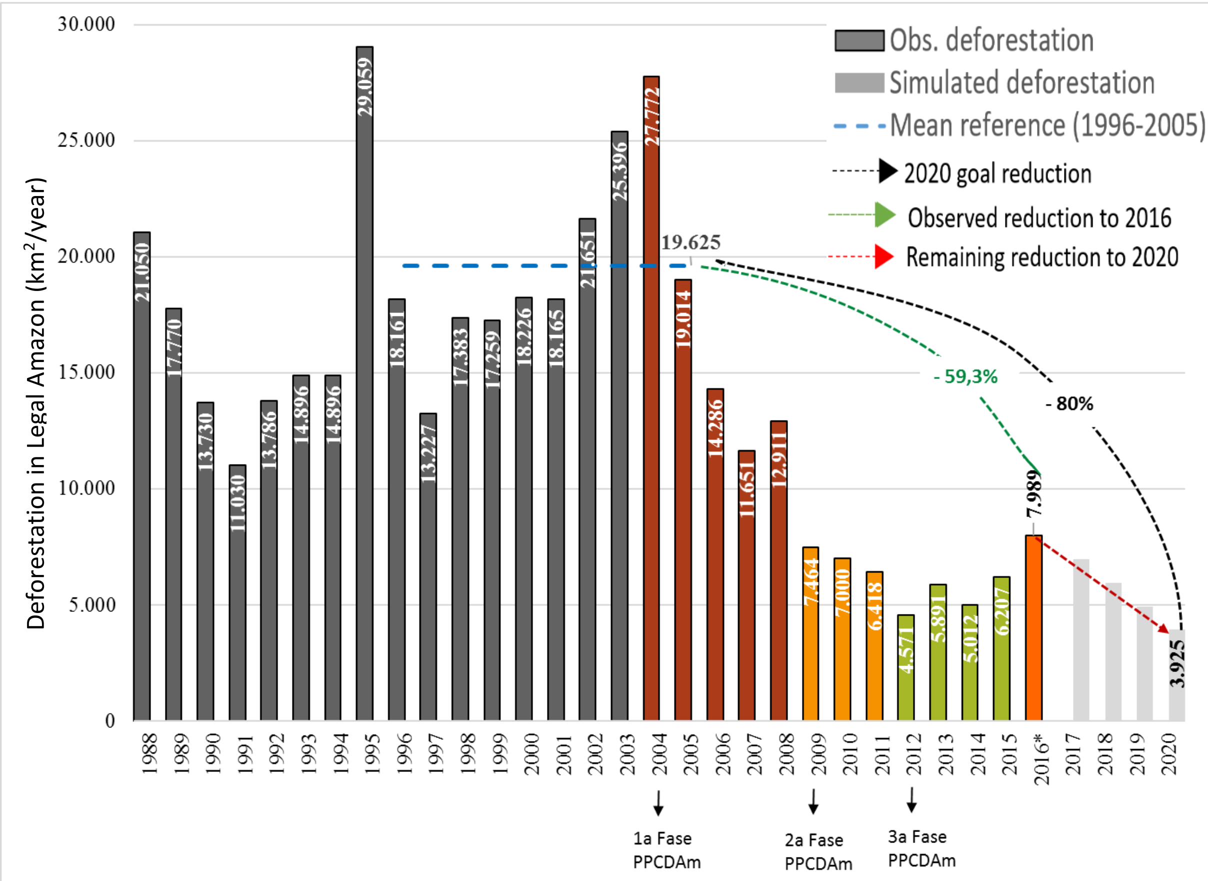


Figure 70: Deforestation reduction goals in Legal Amazon up to 2020

Source: Adapted from PR-CS-GPTI (2013) and MMA (2017).

For the 1996-2005 period, Brazilian government estimates a mean deforestation of 19.625 km^2/year for the Legal Amazon. Erazo (2016) estimated growth rates for the same period using different deforestation growth models. If deforestation trends continue unchanged, by 2020, deforestation rates could have been 25,767 km^2 (logarithmic), 38,850 km^2 (linear) and 50,604 km^2 (exponential). This results show that deforestation rates will continue to increase, in the absence of any governmental intervention. This situation was unsustainable, and an action needed to be taken urgently to prevent further loss of the Amazon biome. In 2003, the government initiated a task force (Grupo Permanente de Trabalho Interministerial), under supervision of the Presidency and the Ministry of Environment, to address the issue. In 2004, the Actıon Plan to Prevent and Control Deforestatıon ın the Legal Amazon (PPCDAm) was promulgated. Between 2004 and 2011, the first and second stages of the Action Plan were carried out. Between 2012 and 2015, the third stage of PPCDAm operated, and the fourth stage was proposed for the period 2016-2020. Some of the results on deforestation are shown in Figure 70.

The Brazilian government defined a commitment to reduce GHG emissions from deforestation in the Brazilian Amazon of up to 80% (reaching 3.925 km^2/year), by 2020, from a baseline calculated on mean deforested area observed during 1996-2005: 19.625 km^2/year.

The action plan was successful, because up to 2012, it reduced deforestation rate to 4.571 km^2, which is equivalent to a 77% reduction, compared to the 1996-2005 deforested area mean. In recent years, deforestation has been increasing, reaching 5.831 km^2 in 2015 and 7.989 km^2 in 2016. This is a rise from the lowest level observed in 2012, but still is a reduction of 60%, compared to the historical reference level established in 2006. This implies an additional effort from the government to keep low deforestation rates and generate an additional 20% deforestation rate reduction (compared to 2006 reference level). However, future reduction implies an additional effort is needed from the government to recover low deforestation rates and generate an additional 50% deforestation rate reduction, if 2016 and 2020 deforestation levels are compared.

Discussion about the role of deforestation and economic growth has been raised for a long time. As analyzed in previous sections, Brazil economic performance has been changing from, agriculture to credit, consumption and commodities, and lately is focusing on infrastructure investments. This different growth model does not relay on deforestation to generate high growth rates. Figure 71 shows that Brazilian GDP has been constantly growing (except for the global crisis years 2008-2009 and recession observed in 2014 and 2015), while deforestation rates are constantly decreasing up to 2012.

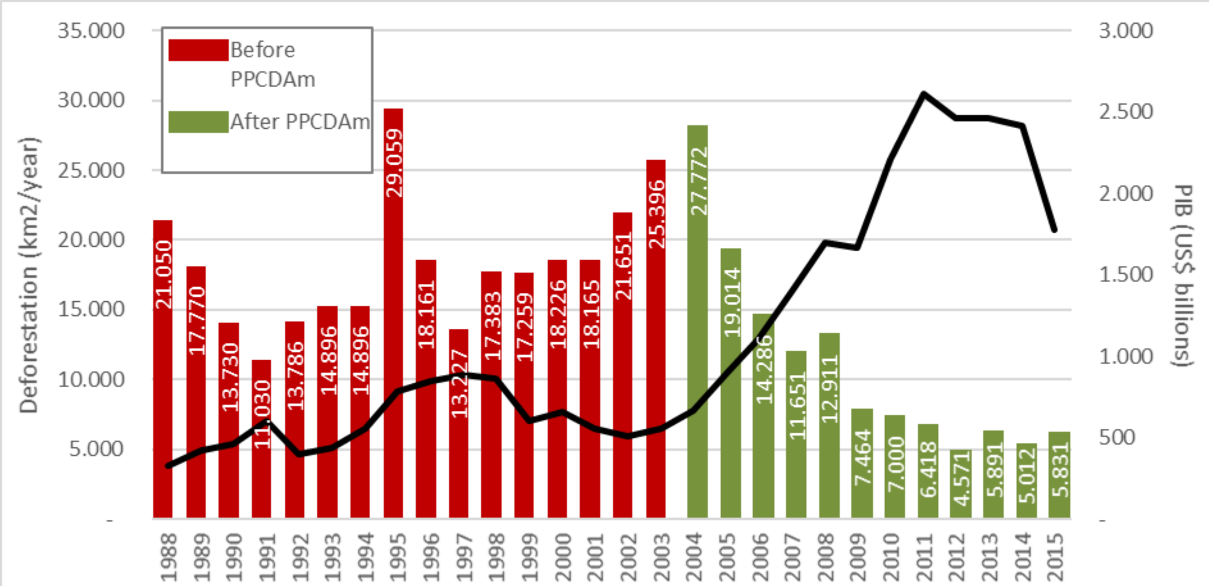


Figure 71: Deforestation and Gross Domestic Product in Brazil, 1990-2015

Source: adapted from PR-CS-GPTI (2013), updated with data from Prodes (2016) and WB (2016).

Although it is difficult to establish a causal relationship between these variables, it is clear that the new development strategy implies that deforestation can´t be seen as a driver of economic growth, at least for the Brazilian case. MMA-SMCQA (2016) showed that agricultural production was correlated with deforestation from 1988 to 2004. After 2004, agricultural production in the Northern Region States continue to grow while deforestation rates reduced, which was a challenge for achieving sustainable development. This result is clearly the consequence of the implementation of PPCDAm.

Brazilian government organized the PPCDAm to tackle deforestation proximate causes, based on a Logical Framework analysis. PPCDAm was structured in three axes up to phase three (2004-2015), and for the fourth phase (2016-2020) it has an additional axis. Four axis are:

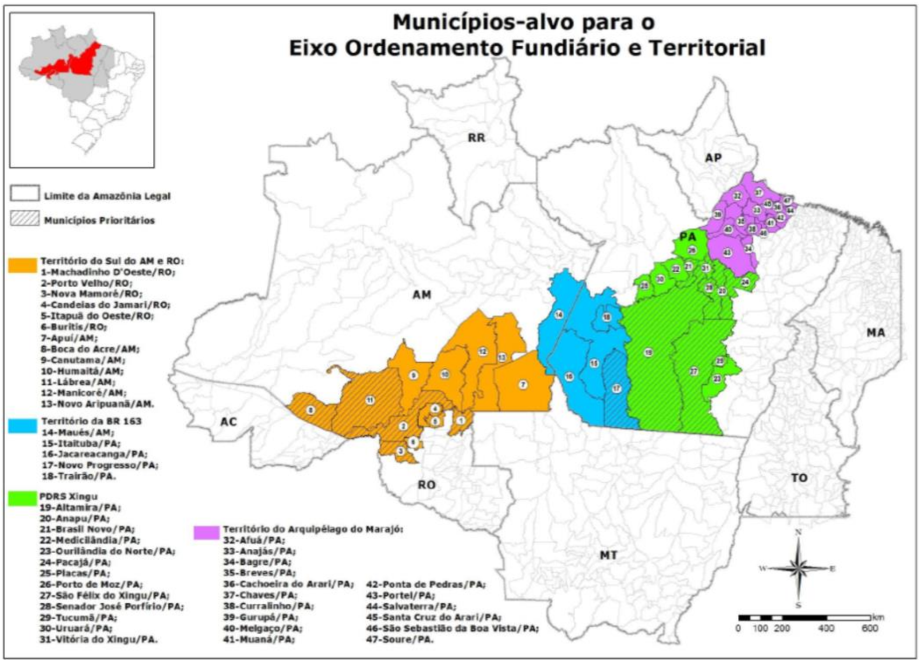
1) Agrarian and land use planning
2) Monitoring and control
3) Sustainable production activities
4) Normative and economic instruments

Instituto de Pesquisa Econômica Aplicada (IPEA), the German Agency for Development (GIZ) and the Economic Commission for Latin American and the Caribbean (ECLAC) made an evaluation on this policy in 2011, and found that up to its second phase (2004-2011), PPCDAm unequivocally helped to reduce deforestation and established a new framework to control illegal deforestation (GIZ, 2011). They also found that main success drivers are related with command and control and new protected areas creation in deforestation threatened areas. One of the evaluating organization's recommendation was that axes related with sustainable production and land use planning need to be reinforced in order to achieve the expected goals. These activities were developed during phase 3 (2012-2015), but understanding that command and control helps to reduce in the short run deforestation, but does not change the structural territory occupation mode, nor change the proximal and structural causes of deforestation.

The plan to focus on prioritized municipalities with higher deforestation rates, and conditioning of credits started in 2008, and it also helped in deforestation reduction (PR-CS-GPTI, 2013).

During the third phase each of the three axis concentrated their efforts on specific municipalities:

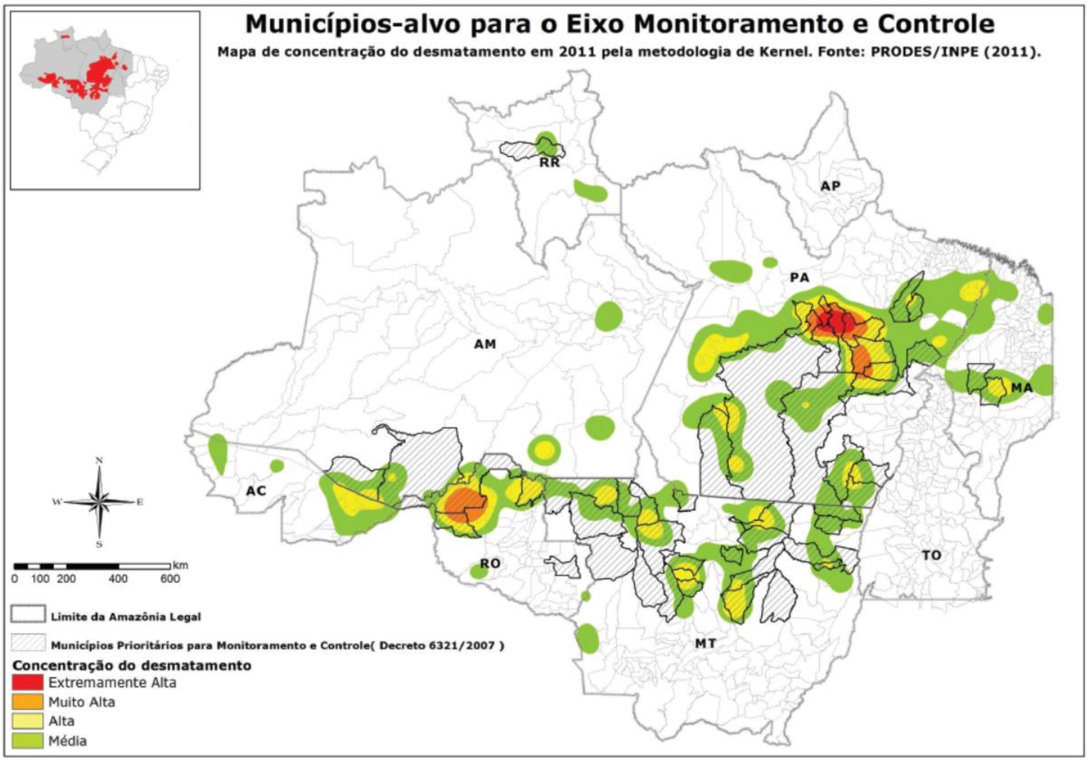
a) Agrarian and land use planning focused on: i) BR-163, in Pará e Amazonas states; ii) Xingu region, in Pará state; iii) southern Amazonas and northern Rondônia states; and iv) Marajó archipielago territory, in Pará state. In total there are 47 municipalities (Map 33)



Map 33: Prioritized municipalities for agrarian and land planning strategy.

Source: PR-CS-GPTI (2013)

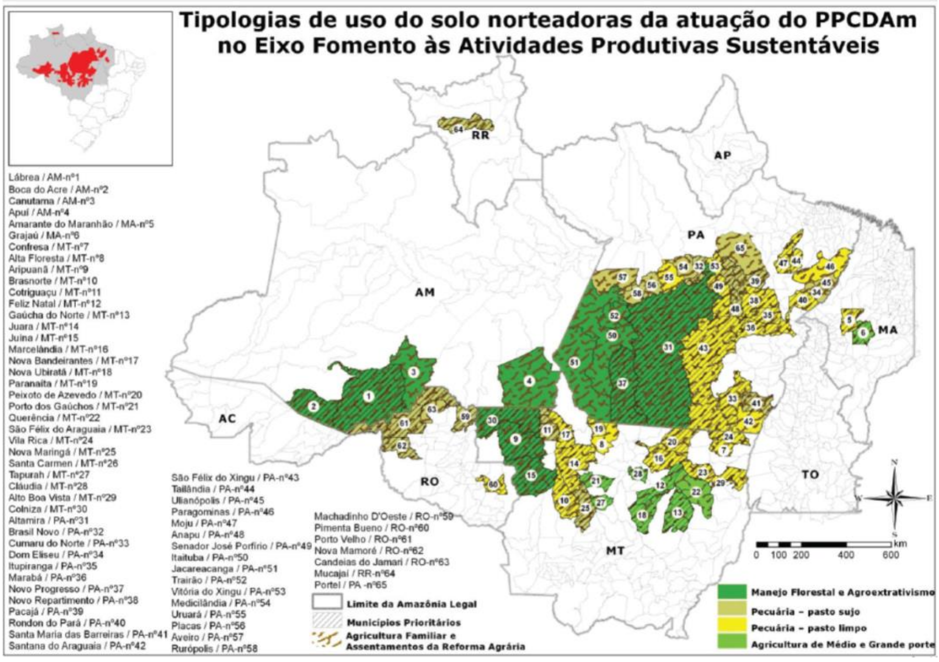
b) Monitoring and control: Due to operational and focus issues, this axis focused on areas where environmental monitoring pointed to greater risks of deforestation expansion using DETER data. Largely, these areas coincide with another prioritization criterion, which is the list of priority municipalities to combat illegal deforestation (Map 34)



Map 34: Prioritized municipalities for monitoring and control strategy

Source: PR-CS-GPTI (2013)

c) Sustainable production activities: this axis focus not only on municipalities with high deforestation, but also on other municipalities that will have a deforestation leakage effect, as a result from reduction deforestation in neighboring municipalities (Map 35). A total of 65 municipalities were prioritized, including other axis municipalities, as well as areas where there are infrastructure works associated to Growth Accelerating Program (Programa de Aceleração do Crescimento - PAC). This program focuses on areas where paving highways and building hydropowers ocurre. Production activities are grouped in five typologies: i) forest management and agroextractivism (12 municipalities); ii) large and medium-sized agriculture; iii) Livestock – pastures with weeds; iv) Livestock – pastures without weeds (26 municipalities); v) family farming and agrarian reform settlements (all municipalities). Within this axis ABC and PRONAF programs are used as financing sources.



Map 35: Land uses for sustainable production activities strategy.

Source: PR-CS-GPTI (2013)

Total PPCDAm budget for the third phase (2012-2015), was $1,4 billion reais, with sustainable production axis having the largest budget (Table 55).

Table 55: Distribution of PPCDAm resources by axis 2012-2015

Axis	Resources
1. Agrarian and land use planning	$R 213
2. Monitoring and control	$R 425
3. Sustainable production activities	$R 789
Total	$R 1.427

Source: PR-CS-GPTI (2013)

Some of the results generated by the PPCDAm implementation between 2004 and 2015 are:

a) 50 million hectares in conservation units, because of implementing Amazon Protected Areas program (ARPA).
b) 10 million hectares from indigenous communities were homologated.
c) Work on prioritized municipalities and implementation of Terra Legal Program, for land titling.
d) Implementation of Low Carbon Agriculture, in particular sustainable cattle ranching.
e) 60.000 families received support from Minimum Price Guarantee Policy for Socio-biodiversity Products Program (PGPM-Bio program).
f) Strengthening of forest concessions: 842.000 hectares handled using this mechanism.
g) Soy moratorium: for soy produced in areas of illegal deforestation within the Amazon.

h) –Implementation of the Rural Environmental Registry (Cadastro Abiental Rural – CAR)
i) Enhancement of monitoring systems: Prodes, Deter, Degrad, Detex and TerraClass.
j) 51.000 families received "green subsidy" (Bolsa Verde)[40].
k) Technical Assistance and Rural Extension program was implemented for sustainable forest management.
l) 80 projects funded to 2015, in the amount of R$ 1,2 billion.

The fourth phase of PPCDAm is under implementation between 2016 to 2020. This period is key because it precedes the Intended National Determine Contributions (INDC), that will start on 2020.

An important issue is that patterns of deforestation are changing as a result of the success of monitoring and control enforcement in Legal Amazon. During COP 21, held in Paris on December 2015, Brazil generated a compromise to have zero illegal deforestation in the Amazon biome by 2030. Even though this compromise is for Amazon biome, it will include also Cerrado biome (MMA, 2016).

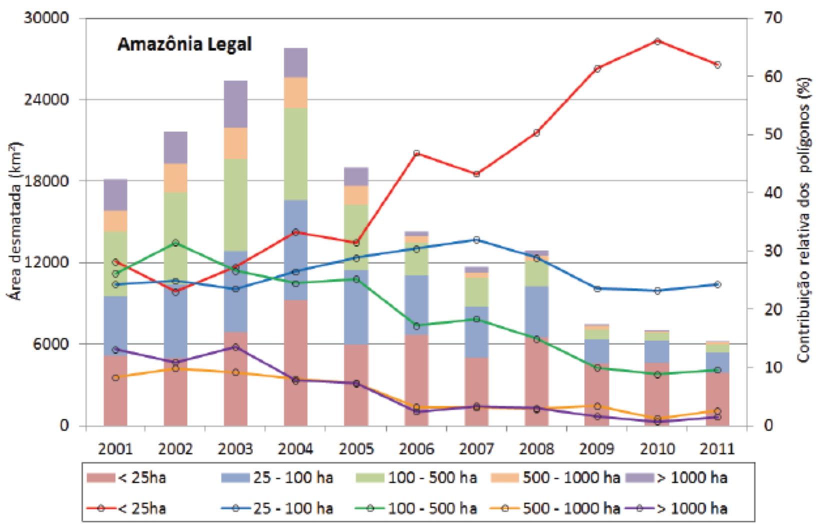


Figure 72: Time series of deforestation by size of deforested area and relative contribution of polygons class area of deforestation to total deforestation (2001-2011).

Source: PR-CS-GPTI (2011)

[40] "Bolsa Verde is an income transfer program for families living in extreme poverty living in areas of relevance to environmental conservation. It works as an incentive for communities to continue to use the territories in which they live in a sustainable way. The program grants R $ 300 reais, every three months, to families who are beneficiaries in areas for environmental conservation, respecting the rules of resource utilization. The benefit will be granted for two years and may be renewed". Source: .http://www.mma.gov.br/desenvolvimento-rural/bolsa-verde

Figure 72 shows that deforestation patterns are changing: there is an increase in small patches, smaller than 25 ha, with a share of 60% of the total; patches with 25 to 100 hectares represent nearly 35% of the total deforested area. The detection system established by the Brazilian government (DETER), is in its limits, because the satellite images that are used to identify deforestation area have a 25 ha resolution (Modis images). To continue with a successful policy there are some changes that need to be done:

1) understanding of spatial and temporal patterns through states and municipalities is needed.

2) a better coordination with policies that are been developed in the region that induce deforestation.

3) strengthening of sustainable production and land planning activities can help to establish a permanent deforestation rate reduction, based on the transition to a new development model.

4) role of Amazon Fund (Fundo Amazonia) as funding source for public policies to combat deforestation

5) generate a regional prioritization

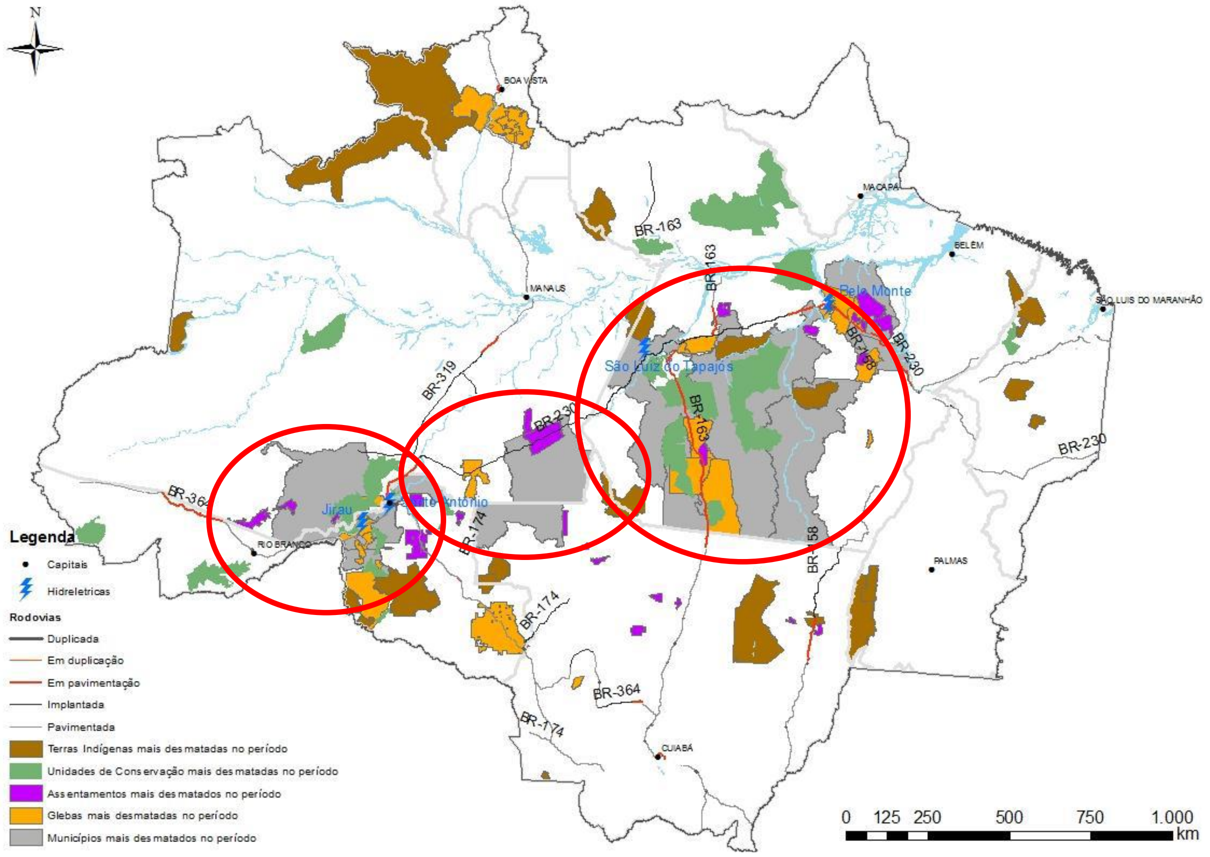
6) keep working with prioritized municipalities.

7) Include actions to be incorporated in the pluri-annual Federal Budgetary Plan (PPA)

8) Strengthen relationships with other federal and civil society organizations.

9) Review of the sustainable production axis, in order to incorporate better coordination with Ministries and non-governmental organizations.

10) Agrarian and land planning axis needs to be better articulated in order to speed up processes and solve bottlenecks; also promote the allocation of public federal lands.



Map 36: Critical areas for deforestation prevention and control in the PPCDAm.

Source: PR-CS-GPTI (2013)

Region 1: "frontier triple" (south of Acre, north of Rondônia and south of Amazonas). Region 2: "north of Mato Grosso" (borders with the south Amazon and Pará). Region 3: Pará (next BR-163, BR-230 AND BR-158).

6.2 Discussion

6.3 Conclusions

This chapter has presented an analysis of the main Brazilian policies related to land-use change in the Brazilian Amazon. Though much effort has been made in the last years, with a relative rate of success in curbing deforestation, there is still room to enhance efforts and, especially, to interlink the diverse initiatives in order to gain efficiency and achieve better results in controlling deforestation and, as such, achieving the targets set by the National Plan on Climate Change.

As regards the National Plan on Climate Change, it can be seen that it has the benefit of setting very clear objectives. Furthermore, there are efforts been conducted by specific policies that envision achieving the defined goals. In particular, the most important policy is the so-called ABC Plan. The ABC Plan, among other features, provides funding for farmers to improve their productive practices and to develop a low-carbon agriculture and cattle-ranching activity. In spite of its aim on developing low-carbon primary sector, the states of the Amazon Legal have a low participation on the total disbursements of the ABC Plan.

In addition, the ABC Plan focuses more on pastures recovery and direct planting and does not give much attention on crop-livestock integration and forests,[41] which, as analyzed before, have a much higher potential to reduce deforestation and to achieve the aims related to CO_2 emissions.

When compared to other lines of rural credit, the ABC Plan is quite small. Total rural credit between 2013 and 2017 amounted $R 779 billion, whereas the ABC Plan accounted for R$ 11 billion. As in the main lines of rural credit, farmers do not need to prove they have legal reserves or any other environmental requirements, the total effect of rural credit is to provide incentives to clear forest. Therefore, although the ABC Plan has interesting features, its capability to generate a real change is very limited.

Another strain of environmental policy is through command and control. In this sense, the PPCDAM has shown a remarkable success, especially until 2012. After this period, the trend of decrease in deforestation has vanished. However, this might be related to a major change in the Forest Code, there is also space to criticize the fact that an important part of PPCDAM has been neglected: the axe of sustainable production could be a helpful instrument in keeping deforestation low as it would mean a shift in economic incentives to clear land. In a scenario of fiscal crisis, as the expenditures on command and control activities are reduced, sustainable production could have represented an important way of keeping deforestation low, as it would mean a shift in economic incentives.

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[41] One should note, however, that it is difficult to find out whether it is a supply-side problem or a demand-side problem.

The Clean Development Mechanisms in Brazil did not achieve any relation with the primary sector. This is very much related with the way the CDM was designed and how developed countries refused to accept land-use change on it. Thus, the CDM was utilized to develop business models linked to emissions reductions in sectors as energy and waste disposal.

Overall, this chapter concludes, based on the analysis of distinct policies related to climate-change, that Brazil has a significant amount of resources devoted to curbing emissions. However, these policies deserve a better coordination. As they are designed by now, it means a waste of resources, since there are other policies that act in the opposite sense. As discussed here, the rural credit policy is helpful in boosting deforestation instead of helping in curbing emissions related to that activity.

7. GENERAL CONCLUSIONS AND RECOMMENDATIONS

Modeling: able to explore alternatives assuming a rational agent, with limited information, and more like post-keynesian. This allow us to generate different prices, without having to define a general equilibrium model, or having all markets at equilibrium

General economy characteristics and in particular market prices evolution for beef, soy, land prices, are important determinants of deforestation projection. We did include some basic biofisical and economic characteristics, but deforestation rates can be adjusted linking transition matrixes to all the variables we analyzed plus market issue. Maybe in that way we would be able to detect the increase on deforestation that started from 2013.

On exploration process was general systems theory to try to endogenize the land owner behavior en terms os land use selection possibilities: how, cellular automata, and evolutionary economics. but this should be done in a later work

Also, incorporate some other ecosystem services characteristics and interactions among them to identify possible trade-offs and complementarities. Increasing reforestation generates reduction of soil erosion, and that generates cost reductions, but in Legal Amazon low population. Maybe proposals like TEEB (2015) or Socio-Ecosystems proposed by the IPEBES, can be explored to do so.

Modelling different land uses and transitions: there is now available for the LA, but fore sure processing capacity needs to be increased, bigger processor. What can be done is not only simulate forest- no forest transitions, but transitions between forests, agriculture, pastures, secondary vegetation. Just adding this variation to the analysis would generate a finer analysis between land uses, not only deforestation.

Different fencing costs: Is one of the most complete for Brazil, but can be updates with more recent prices, and se possibility of downscaling Federal Unit information to municipalities, using transportation costs from capital of each FU to each municipality. The idea behind would be to develop a transportation cost first to main urban areas, and then from main urban areas to cluster of farms.

One of the information that is available and that we explored was from IBGE PPM. We try to explore different type of land users for cattle ranching: small, medium, large; what type of cattle ranching activity is being developed milk, meat (calves, fattening), and what other activities are being developed within the farm agriculture, forest and non-timber forest products.

With this characterization it would be very helpful to identify how incentives can be applied within each farm for specific cattle ranching activities, but also to other complementary activities that can be developed to increase farms profitability from conservation and forest sustainable use.

Our results are part of a proposal for Brazilian Ministry of Environment, for the Technical basis for a National PES. Hopefully some of this results, in particular the SISGEMA model will be used by policy maker to identify priority areas for each Brazilian Biome, and of course for the Legal Amazon, as was shown in this work

Policy coordination based on inter-sectoral interactions. We showed how Agricultural policy can influence a PES scheme for deforestation, reforestation, CO2 emissions reduction from deforestation and reforestation, methane emissions reduction from cattle ranching. We analyzed only one tool and it would be very important do advance in policy mix where other social considerations are taken into account and where non-monetary incentives can be explored. Our preliminary conclusions help to shape PES policy and its main characteristics, but it can be complemented with other non-monetary approaches that star from the policy takers social and political characteristics, institutional analysis from Elinor Ostrom - IED, that take us again to policy mix.

8. ANNEXES

Annex 1: Economic valuation definition and methodologies

For Kumar et al. (2010) economic valuation is defined as "the process of expressing a value of a particular good or service in a certain context (e.g. decision making) in monetary terms." Now for the same authors the assessment in a broad sense is defined as "the process of expressing the value of a particular good or service in a certain context (e.g. decision making), usually in terms of something that can be counted, generally money, but also through methods and measurements of other disciplines (sociology, ecology, among others)". Then, economic valuation is part of a set of methodologies that seek to identify benefits that ecosystems and biodiversity generate for humans.

For de Groot et al. (2002) values associated with environmental goods and services can be: a) ecological, when they are based on ecological sustainability; b) sociocultural, when they are based on fairness and cultural and; c) economic, when based on efficiency and cost-effectiveness. By integrating these types of valuation, it is possible to obtain a total value of Ecosystem Services (ES). In this way, economic valuation is one of many techniques that can help approximate the total value of an ES.

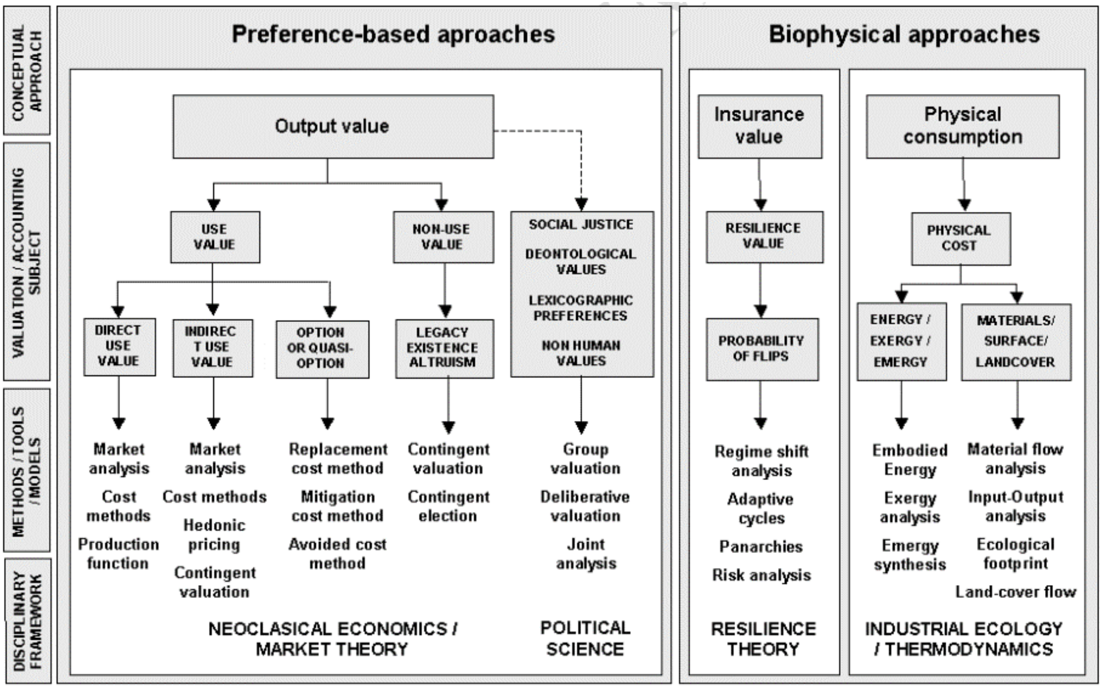


Figure 73: Nature´s values valuation approaches

Source: Pascual and Muradian, 2010

Figure 73 show there are additional methodologies to determine ES values, besides economic tools. For example, there are social justice methods of political science, resilience value of resilience theory, physical cost analysis such as Emergy and Material Analysis, which come from industrial ecology and thermodynamics (Pascual and Muradian 2010).

In some cases, these methods are not easily comparable and are complementarily used to identify the current state of ecosystem services, in a perspective of collaboration between different sciences. Economic valuation seeks to associate a monetary value with changes on economic well-being of a society, because of a small or marginal change in ecosystems (Pascual and Muradian 2010). The economic valuation of environmental goods and services is as a process of finding a total economic value, where the value of an environmental resource is the sum of the goods and services that it provides, regardless whether they have market prices (Pearce, 1994 quoted by CPO Consultoria, 2015). When there are no market prices, methods known as environmental valuation are applied in a way that prevents the loss of these environmental goods and services, when treated by society as zero cost (CPO Consultoria, 2015).

Annex 2: Land rent curves, von Thünen model in the Forest Transiton Theory

Angelsen (2007) used five different land use classifications to explain land rents and deforestation:

I - Intensive agriculture
E - Extensive agriculture
M - Managed forests
O - Open access forests
G- Old growth forest

Land rent of the different land uses (denoted by superscript *i*) is then:

Equation 23: Land rent of different land uses

$$r_i(d)= p_i\ y_i - w\ l_i - q\ k_i - c_i - v_i\ d$$

with i= I, E, M, O, G

Agricultural production per ha (yield) of the homogenous land is given (y), and the product is sold in a central market at a given price (p). Labor and capital required per hectare are l and k, with inputs prices w (wage) and q (annual costs of capital). The cost of enforcing property rights is given as c. For open access forests, c=0. Finally, transport costs per kilometer are denoted as v and the distance from the center is d. This defines the land rent or profit from agriculture as a declining function of distance.

All curves may not necessary exist in one area. The border between extensive agriculture and intensive agriculture defines the intensive margin, while the border between extensive agriculture and forests defines the extensive margin (agriculture-forest frontier). Dynamics along the extensive margin should be the focus to understand deforestation, as the forest-non-forest border is located there. In some cases, the deforestation focus can be between intensive agriculture and forests (i.e. soybean).

Shifts in agricultural rent are explained by higher output prices, good agro-ecological conditions (soil quality, rainfall, temperature), technological progress and intensification, lower off-farm wages, lower input prices, roads (extent and quality) and transport infrastructure (rivers), lower costs of property rights enforcement (higher tenure security), land competition, lower interest rates, access to credit. Factors that increase forestland rents are: higher price of forest products, lower wages (in intensive non-timber forest product activities), technological progress in logging operations, community forest management (they include forest's environmental services in decision-making), and payment for environmental services (Angelsen, 2007). This last factor is critical, because, generating a direct payment to people making decisions on land use (agricultural vs. forest) will change the way they value forests, as payment will change their forest rent equation.

The von Thünen model can also be linked to the FTT. During the first stage, there is a low agricultural land rent and reduced land use changes from forests to agriculture. Then, triggers and reinforcing loops increase agricultural land rent, generating an increase on deforestation (high deforestation), during the second stage (agricultural frontier). Later, a weakening of these forces generates a reduction of agricultural land rents, an increase of forestland rents (or both), resulting in deforestation slowdown and eventually reforestation.

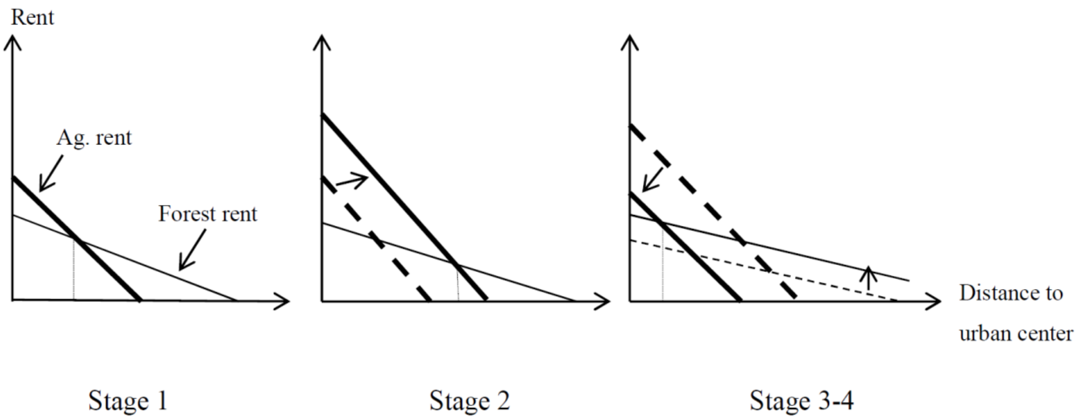


Figure 74: Changes in rent curves during the forest transition

Source: Angelsen (2007) and Robertsen (2011)

FTT suggests that forest cover stabilization occurs mainly by two forces: a) economic development, increasing labor opportunity-costs (reducing agricultural rent) and b) higher demand and prices for forest products (increase in forest rent). Angelsen (2007) concluded that trying to stabilize forest cover during the forest frontier stage (stage 2) would generate conflicts with poverty reduction policy objectives; reduction of agricultural rent (through reduction of market and capital access), has a negative effect on rural income. The mechanisms that help stabilize forests during the next stage (stage 3-4) are more compatible with poverty reduction, as they focus on higher rural wages and higher prices for forest products. Recognition of NTFP and environmental services, have the potential of producing win-win solutions.

Annex 3: Agricultural household models and effect of different variables on deforestation

Main agricultural household models characteristics are (Taylor and Adelman, 2003):

a. Production and consumption decisions are linked because the deciding entity is both a producer, choosing the allocation of labor and other inputs to crop-production, and a consumer, choosing the allocation of income from farm profits and labor sales to the consumption of commodities and services.

b. Farm profit included implicit profits from goods produced and consumed by the same household, and consumption included both purchased and self-produced goods.

c. As long as perfect markets for all goods, including labor, exist, the household is indifferent between consuming own-produced and market-purchased goods. By consuming all or part of its own output, which could alternatively be sold at a given market price, the household implicitly purchases goods from itself. By demanding leisure or allocating their time to household production activities, it implicitly buys time, valued at the market wage, from itself.

d. This model applies to all but agribusiness-operated commercial farms, which consume a very small share, if any, of their own output and supply few, if any, of their own inputs.

e. Household’s objective is to maximize a discounted future stream of expected utility from a list of consumption goods including home-produced goods, purchased goods, and leisure, subject to what may be a large set of constraints (cash income, family time and endowments of fixed productive assets, and production technologies)

f. Prices of inputs, outputs, and non-produced consumption goods are constrains fixed exogenously, or when there are missing markets (i.e. household non-tradables), they specify an internal “shadow price” determination condition.

g. Most agricultural household models are static (eliminating “discounted future stream of” (from the preceding sentence)

h. AHM assumes that prospects are certain or, equivalently, that households are risk neutral.

i. In household-farm models the household budget is endogenous and depends on production decisions that contribute to income through farm profits

j. The solution to a household-farm model yields a set of core equations for outputs, input demands, consumption demands, and either prices (for household non-tradables) or marketed surplus (for household tradables).

k. The solution to AHM is a set of dependent or endogenous variables as functions of exogenous variables (prices of tradables, farm assets, household time constraint, other household characteristics), usually including some that may be influenced by policy (e.g., government-set prices for staples or cash crops). The form of this solution, particularly the interactions between production and consumption that are a characteristic of household-farm models, are extremely sensitive to assumptions about the extent to which households are integrated into product and factor markets.

l. Family labor can be perfectly substitute in local labor markets by households —and conversely, that it can sell its own labor at a given market wage. As a result, households can hire more workers to fill the resulting excess demand for labor, increasing production and consuming more leisure.

Some extensions of the agricultural household model include some biophysical characteristics like forests and soil quality, to introduce some of the environment characteristics into the decision-making process. Erazo (2001), used forest regeneration and land availability as restrictions into a consumption maximization problem for a peasant, using family labor to produce agriculture goods. The interesting proposal here lies in the interactions between forests and agricultural land: actual agricultural land fertility increases with higher forest cover, but agricultural land increases positively with deforestation, which in turn affect negatively forest remnants and then land fertility. The solution to the problem is the amount of labor assigned for on farm activities and the consumption of different goods (wood an agricultural product). This in turn will define the amount of forest and agricultural land at farm level (Erazo, 2001).

Those models were used to analyze different household decision like nutrition in farm productivity, agricultural technology adoption, labor supply choices (LaFave and Thomas, 2012) and different policies based on comparative statistics, with theoretical or parameterized models (Taylor and Adelman, 2003), and results of different changes of variables like population, productivity, transport costs and allocation of land titles (Angelsen, 1999). What these models have in common is use of neoclassical view of decision making by agricultural households, where the solution of the model is one similar to the central planner of a country economy or a situation in which there are no markets for food or labor (see Figure 75).

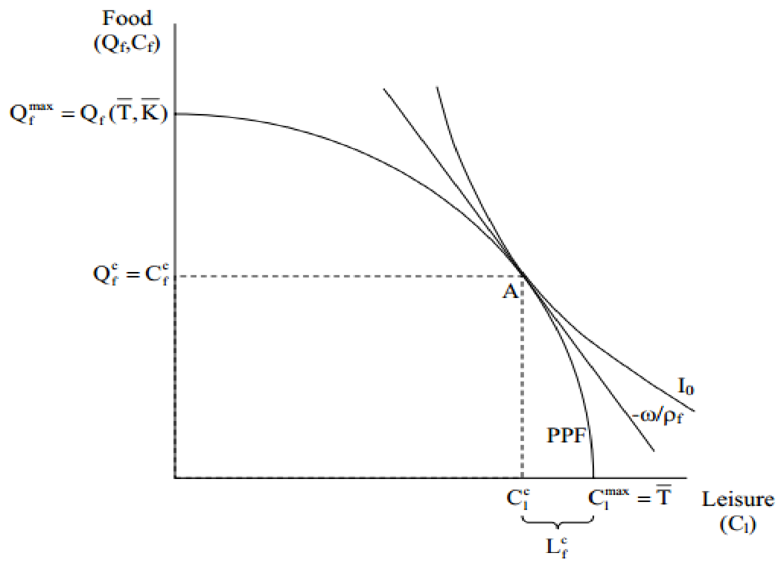


Figure 75: Agricultural household with missing markets.

Source: Taylor and Adelman (2003).

Q_f= food produced, C_f= food consumed, C_1 = leisure, PPF = production possibility frontier, I_0= utility form goods consumption, L_c^f= family labor allocated to production activities, p_f=price of food, ω=shadow price of leisure, T= total amount of available household time.

Angelsen et al. (2001) make a similar analysis starting with complete markets (labor and market goods) with no transaction costs, and found that "technological progress in frontier agriculture makes it more profitable and therefore leads farmers to expand into forests". Later, they go to a situation where there are incomplete markets, because of transaction costs, inexistent markets or inability to share risks. They found that innovations that allow farmers to use less of their scarce resource would boost deforestation. In addition, for labor-missing markets, the amount of labor used will depend on the total cultivated area, labor intensity, and will be constrained by the total amount of available family labor force. This in turn will determine the ability to incorporate new production areas, through deforestation. If a pure increasing yield technological change is considered, total result on deforestation will depend on two situations: a) increasing yields will imply more labor, and hence less time on non-productive activities (substitution effect), increasing deforestation; b) higher yield implies additional income that allows taking more leisure time, assign less labor, and reducing deforestation. Some of these assumptions for different model structures like subsistence (fully belly), Chayanovian (Labor market constrained), open economy and private property and open economy and open access models, and results on deforestation are summarized in Table 56 and Table 57.

Table 56: Different assumptions for subsistence, chayanovian, private property and open access models.

Model	Households' objective: utility maximization	Labour market	Property rights regime
I: Subsistence ('full belly')	Minimize labour, given subsistence target (lexicographic)	No labour market	Private (or communal)
II: Chayanovian	Trade-off between consumption and leisure above subsistence level	Labour market exist, but households are quantity constrained	As above
III: Open economy, private property	As above, but reduces to profit maximization	Perfect labour market	As above
IV: Open economy, open access	As above	As above	Open access; property rights established by forest clearance

Source: Angelsen (1999)

Table 57: The effect on deforestation of various factors in different models.

Effect on deforestation of an increase in:	Model			
	I. Subsistence ('full belly')	II. Chayanovian	III. Open economy, private property	IV. Open economy, open access
Population (N)	Increase	Increase	No effect	No effect
Subsistence requirement ($c^{\min}$)	Increase	Increase	n.a.	n.a.
Productivity or output prices (x)	Reduce	Reduce (poor) Increase (rich)	Increase	Increase
Transport (distance) costs (q)	No effect	Reduce	Reduce	Reduce
Alternative employment (E or w)	n.a.	Reduce	Reduce	Reduce
Discount rate (δ)	n.a.	n.a.	n.a.	Reduce
Land tenure security ($1-\lambda$)	n.a.	n.a.	n.a.	Increase
Expectations about future productivity or output price (g)	n.a.	n.a.	n.a.	Increase

n.a. = not applicable.

Source: Angelsen (1999).

In these tables, we can see that the result of a change of a variable varies depending on the type of model considered. An increase of population in subsistence and Chayanovian models increases deforestation, while, in the open economy with private property and open access over land and virgin forests, there is no effect.

Annex 5: Business as usual (BAU) vs. sustainable ecosystem management (SEM)

An important issue arises when trying to identify impacts on human well-being from costs and benefits of action and inaction. Presenting policy makers with economic data on ecosystem services, the relation with sectorial productivity, and the existence of potentially more profitable alternatives management practices will fill the gap of existing information on ES values and externalities (Bovarnick and Alpizar, 2010). Bovarnick and Alpizar (2010), proposed an analytical framework to identify two contrasting situations for identifying costs and benefits for different situations related with ecosystems management:

a) Business as Usual (BAU) scenario: a more conventional set of natural resources management practices that optimizes short-run (< 10 years) gains without consideration to economic values of ecosystems or to externalization of their impacts or costs, it does not refer to all activities but to all that deplete or damage ES.

b) Sustainable Ecosystem Management (SEM): a set of practices concerned on long-term output (10 to 20 years), inclusive of all impacts and costs; avoids ES degradation, generating a long-term flow of ecosystem goods and services, as strategy to realize in a cost-effective way long-term profits.

ES under analysis are those that generate goods and services for human use. Therefore, all the ES that help to produce different economic processes are considered. Some practices that maintain or increase ES are grouped under SEM scenario, while, those that degrade ES and rely on other inputs like capital, labor or technology are grouped under BAU scenario.

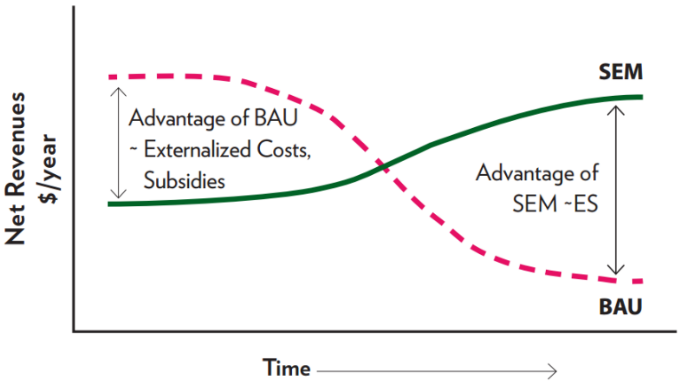


Figure 76: Evolution of net revenues under BAU and SEM

Source: Bovarnick and Alpizar (2010)

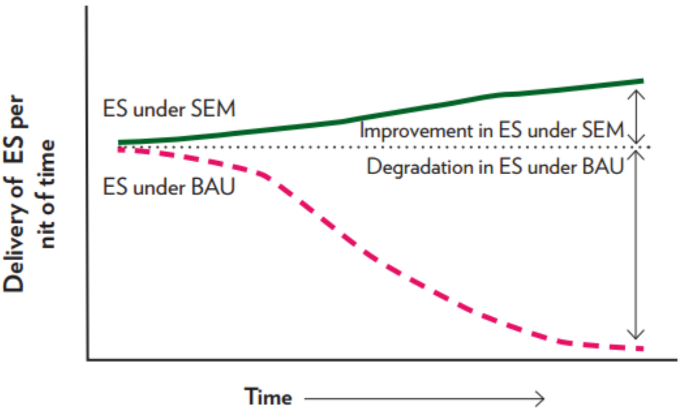


Figure 77: Changes in ecosystem services (ES) under BAU and SEM

Source: Bovarnick and Alpizar (2010)

Previous graphs show different advantages of SEM scenario over BAU. In the short run BAU practices are more profitable because they present externalized costs or subsidies that are generating higher revenues per hectare than a SEM practice will generate. On the long run, practices under BAU will degrade different ES, and their ability to generate services for humans. For example, extensive cattle ranching or monocultures will produce a depletion of soil nutrients throughout time, but these activities are profitable as a result of fertilizers subsidies, or policies that grant titles when a certain percentage of a land is forest clear. The consequences are clear in terms of profitability: net returns will continue to drop to a minimum level (see Figure 78).

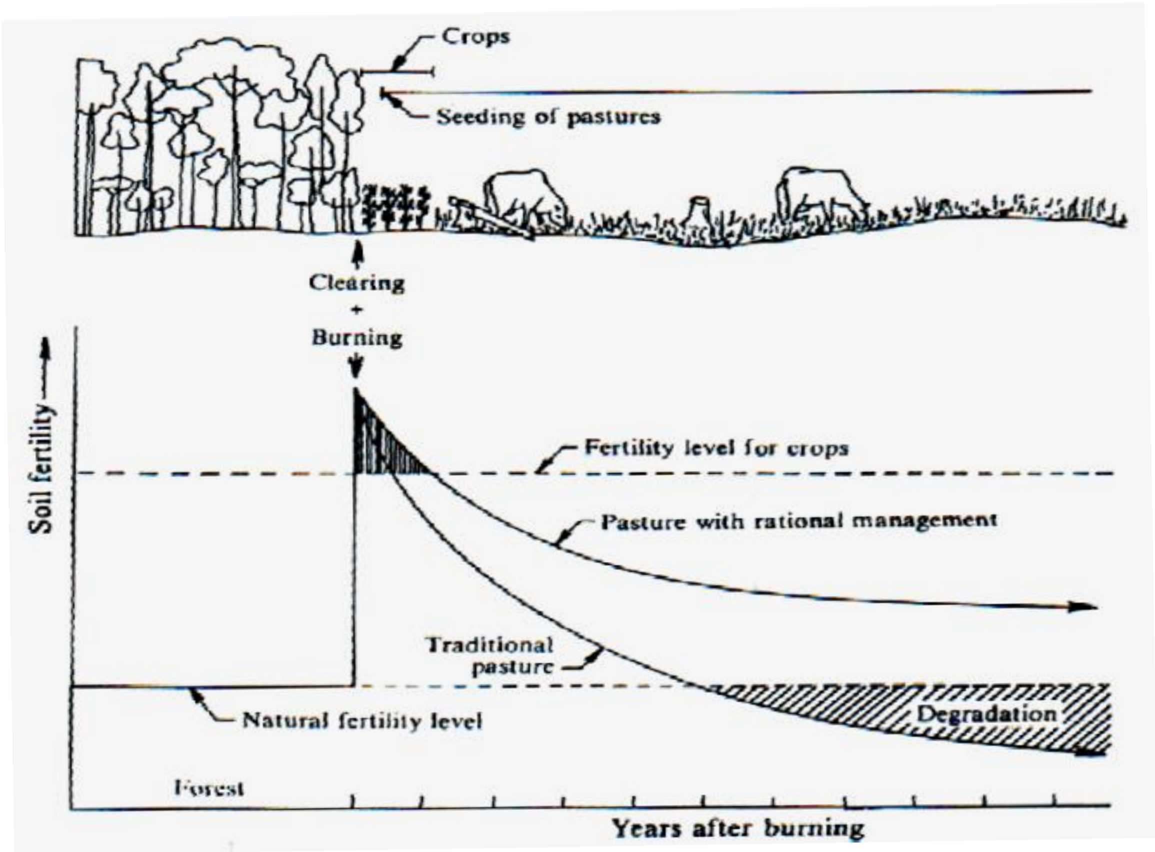


Figure 78: Model of pasture degradation illustrating the evolution of soil properties under grazing using varying management strategies

Source: Anon (1998)

In contrast, under SEM practices, it is possible to find lower net revenues in the short run because of higher implementation costs for a particular technology, but with a higher delivery of ES on the long run. The impact on economic revenues in the long run is clear: the improved ES impact production activities through higher yields or lower production costs, in terms of less inputs use. This is the case for coffees growing areas, where deforestation to establish new production areas has stopped, plantations are placed near forests, and producers perceive higher yields, partially because forests support pollinators (Bovarnick and Alpizar, 2010).

Finally, policy considerations can be included, as the influence on costs and revenues, and markets, from public policy and public agencies influence. As shown before, these types of interventions can explain the higher short-run profitability of BAU practices over SEM activities. There for it is possible to identify the impact of perverse incentives when comparing net economic benefits of BAU and SEM. A similar proposal for policy analysis can be found in Murray-Rust et al (2014) from a systems dynamic point of view (see figure below).

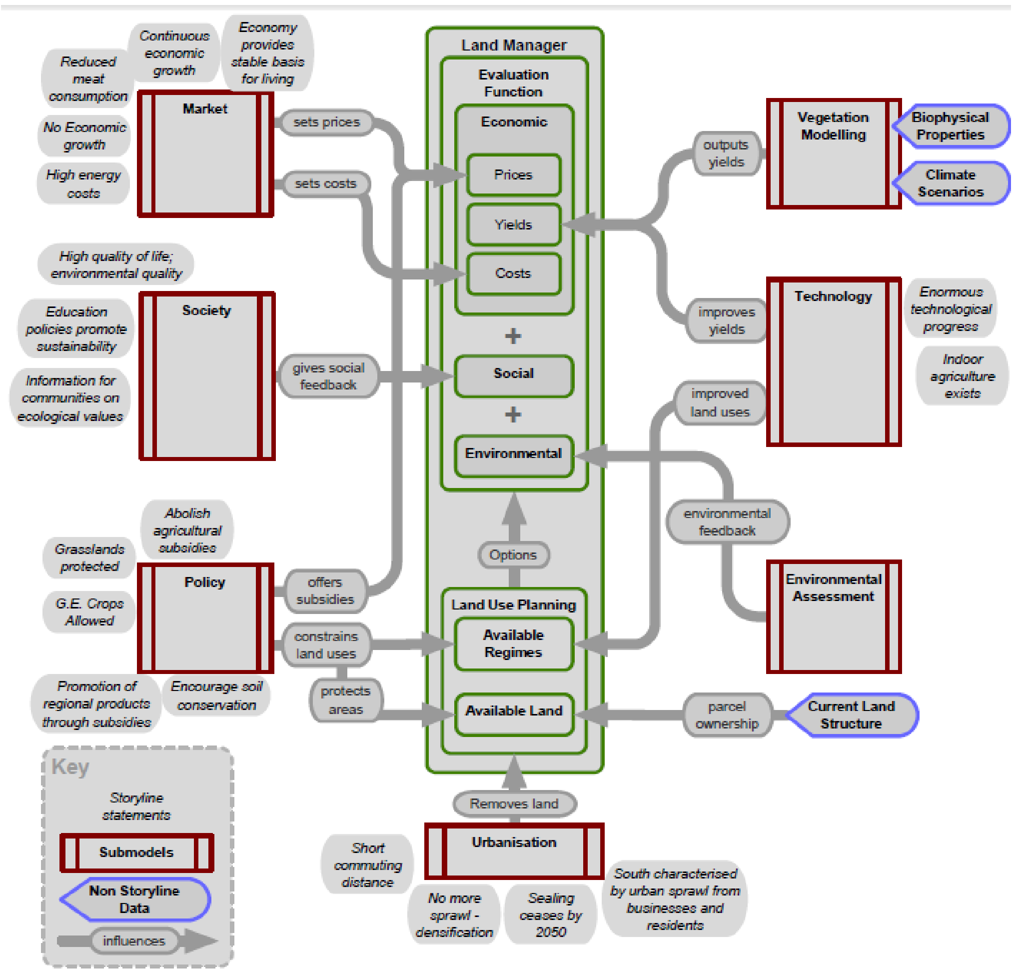


Figure 79: Basic elements for an agent based modeling framework for agricultural land use

Source: Murray-Rust et al. (2014)

Annex 6: Deforestation exponential decay functions by biome

For each case t=0 corresponds to year 2000.

Amazônia: $y = 5.450{,}109 * e^{-0{,}127*t}$

Pampa: $y = 383{,}09 * e^{-0{,}077*t}$

Caatinga: $y = 268{,}7 * e^{-0{,}018*t}$

Cerrado: $y = 1.154.537{,}289 * e^{-0{,}008*t}$

Mata Atlântica: $y = 9.446.583{,}138 * e^{-0{,}481*t}$

Pantanal: $y = 3.981{,}8 * e^{-0{,}069*t}$

Annex 7: Sources for fencing and reforestation costs.

Five studies with input's quantities and were identified for fencing costs: poles, stretchers, wire, chips and labor. The studies with relevant information were: De Andrade (2012), Plaster et al. (2008), Cury & Carvalho Jr. (2011), Silva, Cavalcante & De Araújo (2011).

The following table identifies the work on recovery with native species in different Brazilian biomes.

Table 58: Reference costs for vegetation cover recovery per biome

		Inputs									
Source	Biome	Labor	Equipment	Seedlings	Seeds	Wire	Fence posts	Strethcers	Agrochemicaals	Chemical/organic	Soil conditioner
Cury e Carvalho (2011)	Amazon	x	x	x	x	x	x	x	x	x	
Plaster et al. (2008)	Amazon			x		x	x	x		x	x
TNC (2013)	Amazon	x	x	x					x	x	x
Junior et al (2008)	Amazon			x						x	
Deprá et al (2009)	Mata Atlântica	x		x						x	x
Rodigheri, H. R. (2000)	Mata Atlântica	x	x	x					x	x	
De Andrade, T. (2012)	Mata Atlântica	x	x	x	x	x				x	x

Silva, Cavalcante e De Araújo (2011)	Cerrado	x	x	x			x		x	x	
MMA (n.d.)	Cerrado	x	x	x		x	x	x	x	x	x
Corrêa e Ferreira (2007)	Cerrado			x							
Silveira e Coelho (2008).	Cerrado			x		x	x	x	x	x	

Source: own elaboration

In addition to the information on the most used inputs for the recovery of native vegetation and the quantities of these inputs per hectare, we consulted twelve studies on the forest species that specialist recommend for recovery in the different Brazilian biomes. Studies found with suggestions of different forest species, by biome are presented in the following table.

Table 59: Sources consulted on reforestation species

Biome	Source	Species
Mata Atlântica	Nave, Rodrigues, e Brancalion (2012)	Initial, medium and final wood, additional
Mata Atlântica	Rodrigues, Brancalion e Isernhagen (2009)	Initial, medium and final wood, additional
Mata Atlântica	De Andrade (2012)	According to terrain: arid, semi-arid, humid, sub-humid
Mata Atlântica	Castro, Mello, and Poester (2012)	Pioneer, secondary, climatic
Mata Atlântica	Noffs, Galli, e Gonçalves (2000)	Pioneer, definitive
Mata Atlântica	Moraes et al. (2013)	Pioneer, initial secondary, late secondary, climax; Lowland forest, mountain forest, seasonal forest.
Amazônia	TNC (2013)	Coating, diversity, intolerant to shade, commercial potential
Cerrado	Corrêa e Ferreira (2007)	Pioneer, secondary, climax, Pioneer, secondary, climax, heliophyte, mesophytic forest, gallery forests, Cerrado, Cerradão, campos, Brejo; survivial percentage.

Caatinga, Mata Atlântica, Amazônia	Cerqueira e Carvalho (2007)	Pioneer, non-pioneer, rarely flooded, periodically flooded.
Pampa	Tatsch (2011)	Pioneer, secondary.

Source: own elaboration

After estimating the amount per hectare of recommended seedlings for the recovery of the different Brazilian biomes by forest species, current prices were identified for agricultural inputs, such as fertilizers, herbicides, insecticides and pesticides. Some suppliers of seedlings for forest areas reforestation were also consulted in order to know not only the values of the seedlings, but also the costs of labor for the reforestation activities. Inputs have different levels of aggregation: some have national coverage, others have state coverage, and very few have municipal coverage, as can be seen in the following table.

Table 60: Sources consulted for agricultural inputs and labor costs.

Data	Source	Coverage	Measurement unit
Fertilizer prices	IEA-SP (2015)	Municipality (for São Paulo state)	BRL$/kg
Fertilizer prices	Epagri-SC (2015)	State (Santa Catarina)	BRL$/kg
Fertilizer prices	SAA-PR (2015)	State (Paraná)	BRL$/kg
Fertilizer prices	CONAB (2015)	State (BA, CE, DF, ES, GO, MA, MG, MS, MT, PI, RO, RS, TO)	BRL$/kg
Fertilizer prices	BN (2015)	National	BRL$/kg
Herbicide price	IEA-SP (2015)	Municipality (para todo estado de São Paulo)	BRL$/kg or BRL$*/l
Herbicide price	Epagri-SC (2015)	State (Santa Catarina)	BRL$/kg or BRL$*/l
Herbicide price	SAA-PR (2015)	State (Paraná)	BRL$/kg or BRL$*/l
Herbicide price	CONAB (2015)	State (BA, DF, ES, GO, MA, MG, MS, MT, RO, RS, TO)	BRL$/kg or BRL$*/l
Herbicide price	BN (2015)	National	BRL$/kg or BRL$*/l
Insecticide price	IEA-SP (2015)	Municipality (fpor São Paulo)	BRL$/kg or BRL$*/l
Insecticide price	Epagri-SC (2015)	State (Santa Catarina)	BRL$/kg or BRL$*/l
Insecticide price	SAA-PR (2015)	State (Paraná)	BRL$/kg or BRL$*/l
Insecticide price	CONAB (2015)	State (BA, DF, ES, GO, MA, MG, MS, MT, RO, RS, TO)	BRL$/kg or BRL$*/l

Insecticide price	BN (2015)	National	BRL$/kg or BRL$*/l
Fungicide prices	IEA-SP (2015)	Municipality (for São Paulo state)	BRL$/kg or BRL$*/l
Fungicide prices	Epagri-SC (2015)	State (Santa Catarina)	BRL$/kg or BRL$*/l
Fungicide prices	SAA-PR (2015)	State (Paraná)	BRL$/kg or BRL$*/l
Fungicide prices	CONAB (2015)	State (BA, DF, ES, GO, MA, MG, MS, MT, RO, RS, TO)	BRL$/kg or BRL$*/l
Fungicide prices	BN (2015)	Nacional	BRL$/kg or BRL$*/l
Agriculture labor price	IEA-SP (2015)	Municipality (for São Paulo state)	BRL$/month
Agriculture labor price	Epagri-SC (2015)	State(Santa Catarina)	BRL$/month
Agriculture labor price	SAA-PR (2015)	State (Paraná)	BRL$/month
Seedlings' price	IEA-SP (2015)	Municipality (for São Paulo state)	BRL$/ seedling
Seedlings' price	Epagri-SC (2015)	State (Santa Catarina)	BRL$/ seedling
Seedlings' price	SAA-PR (2015)	State (Paraná)	BRL$/ seedling
Seedlings' price	IBF (2015)	National	BRL$/ seedling
Seedlings' price	Fruticultura Viçosa (2015)	National	BRL$/ seedling

Only in two cases (São Paulo and Santa Catarina) was it possible to obtain information on costs of agricultural inputs and labor at the municipal level. In other cases, there is state information, however, it has to be taken into account that the data obtained reflected the variances between the different states.

In the SISGEMA database, which accompanies this document, it is possible to find the different tables of forest recovery costs of the studies mentioned in Table 17, and a list of the reforestation suggested species.

Annex 8: Agribusiness agricultural expansion by main crops.

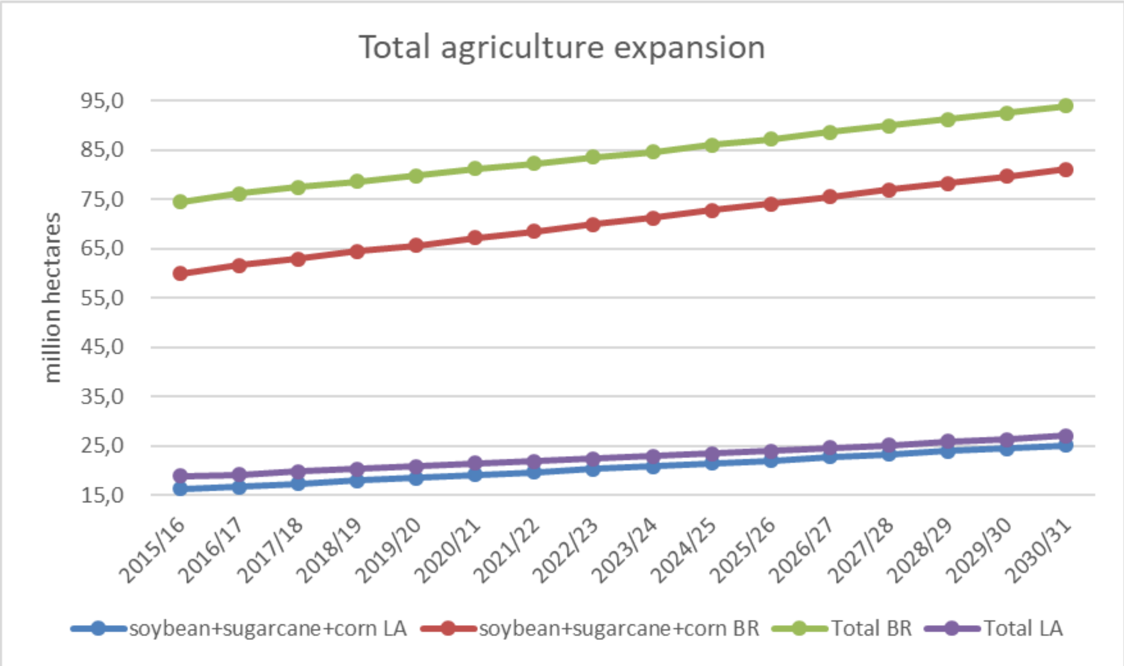


Figure 80: Total agriculture area expansion in Brazil and Legal Amazon. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

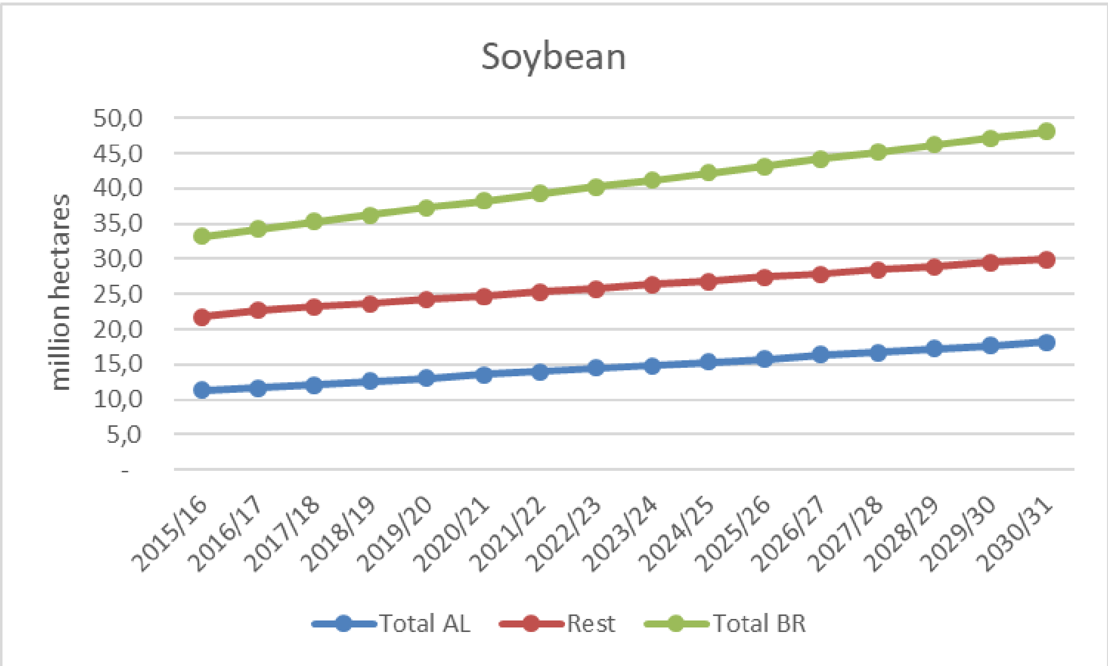


Figure 81: Soybean expansion in Brazil, Legal Amazon. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2015 -2030, author's calculations.

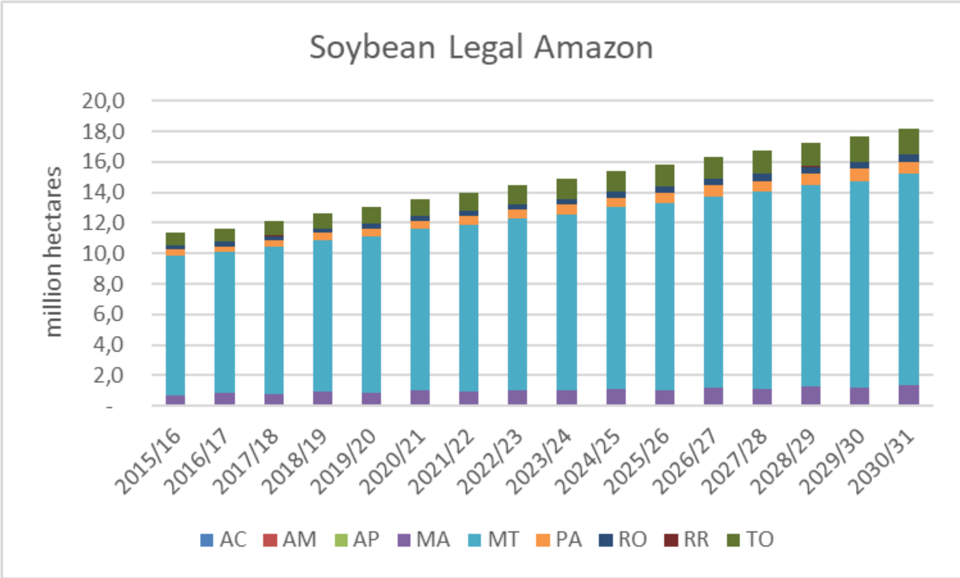


Figure 82: Soybean area expansion in Legal Amazon states. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2015 -2030, author's calculations.

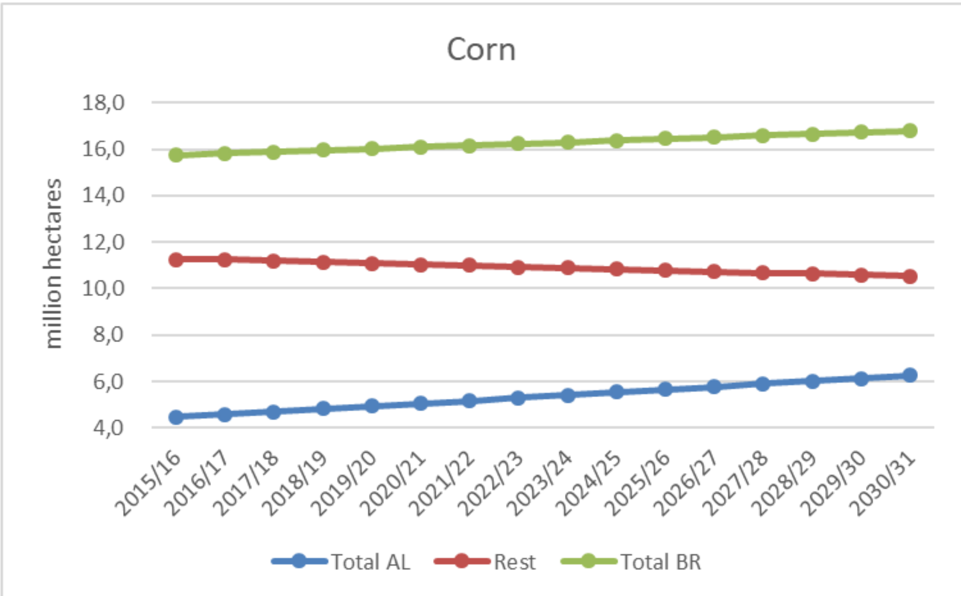


Figure 83: Corn area expansion in Brazil and Legal Amazon. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2015 -2030, author's calculations

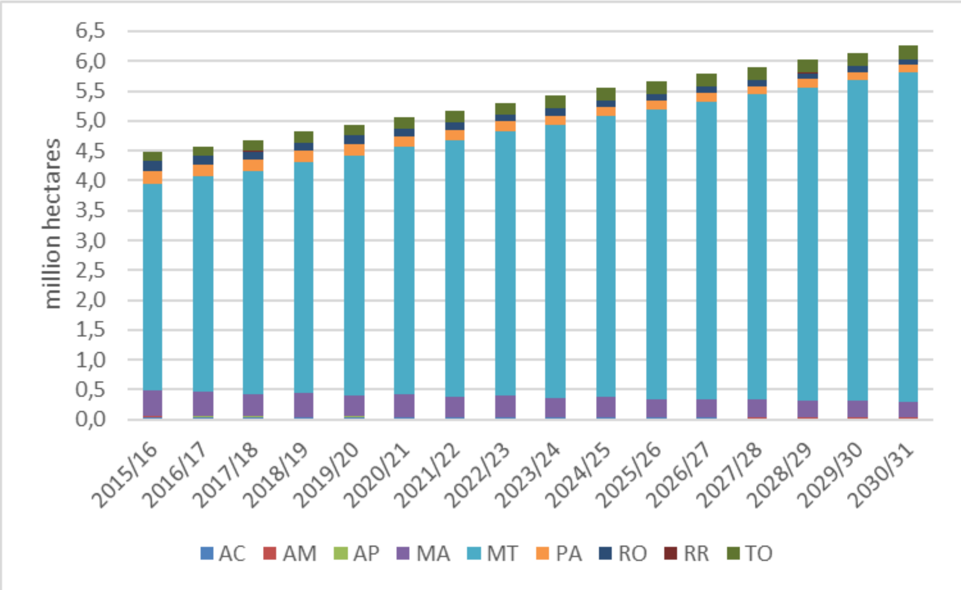


Figure 84: Corn area expansion in Legal Amazon states. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

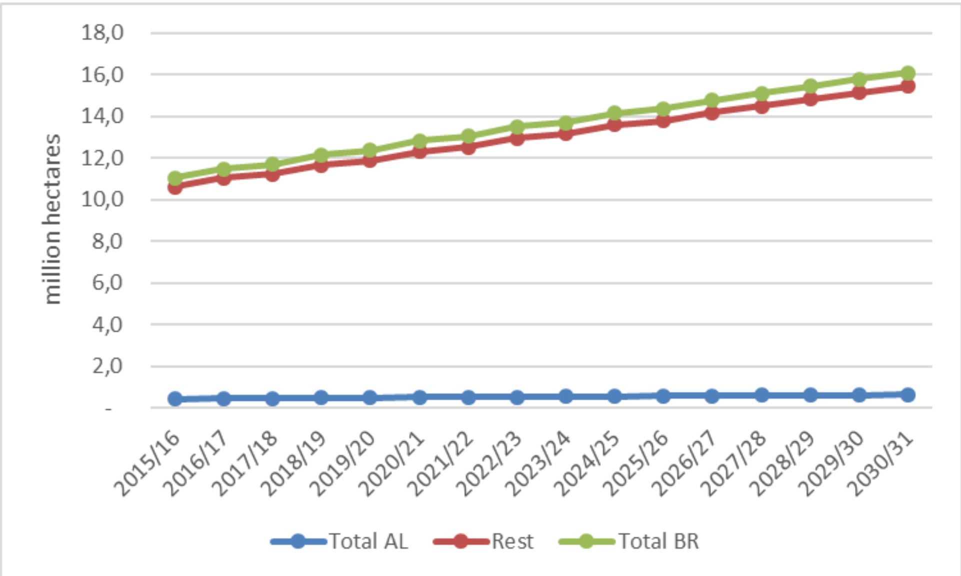


Figure 85: Sugar cane area expansion in Brazil and Legal Amazon. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations

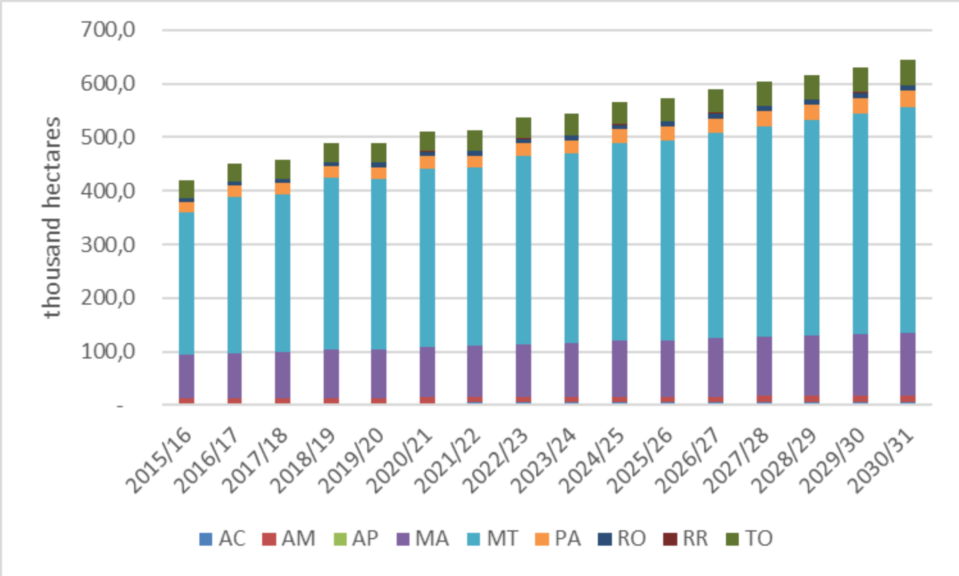


Figure 86: Sugarcane area expansion in Legal Amazon states. 2015-2030.

Source: 2015-2025 adapted from MAPA-SPA (2016). 2025 -2030, author's calculations.

Annex 9: Forest frontier municipality classification using cluster analysis

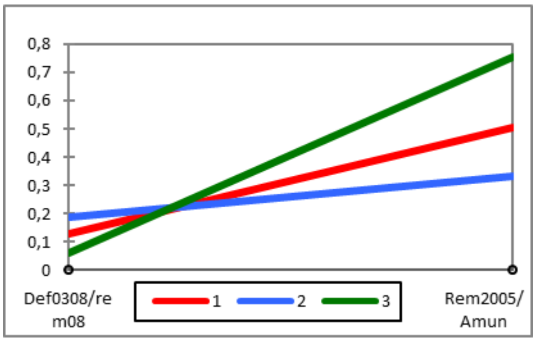
A cluster analysis was made to try to identify if it was possible to classify LA municipalities using two variables associated to the Forest Transition Theory: share of deforestation between 2003 and 2008 (Def0308) on 2008 forest remnants (rem08) and share of 2005 forest remnants (Rem2005) on total municipality area (Amun).

Table 61: Centroids for each class in the forest frontier for Legal Amazon municipalities

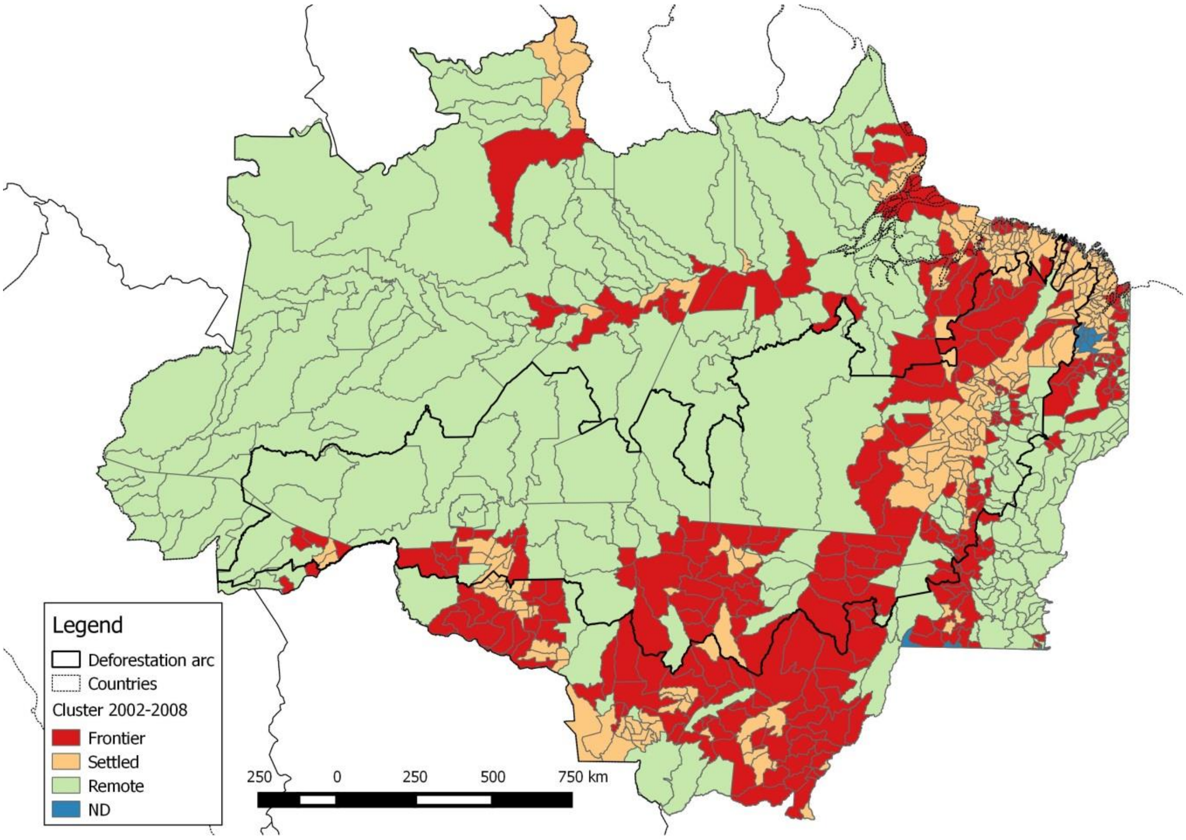
Class	Des0308/rem08	Rem2005/Amun	Sum of weights	Intraclass variance
1 = Frontier	0,133	0,540	261,000	0,017
2 = Settled	0,197	0,189	241,000	0,042
3 = Remote	0,044	0,855	259,000	0,009

Source: cluster analysis

Figure 87: Class profile for forest frontier municipalities in LA



Source: cluster analysis



Map 37: Legal Amazon municipalities' classification on forest frontier using cluster analysis.

Source: cluster analysis

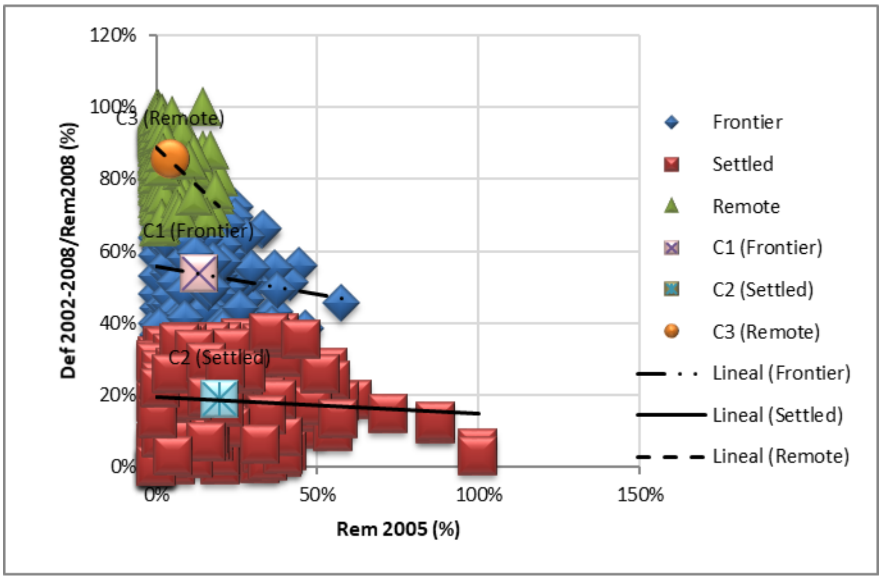


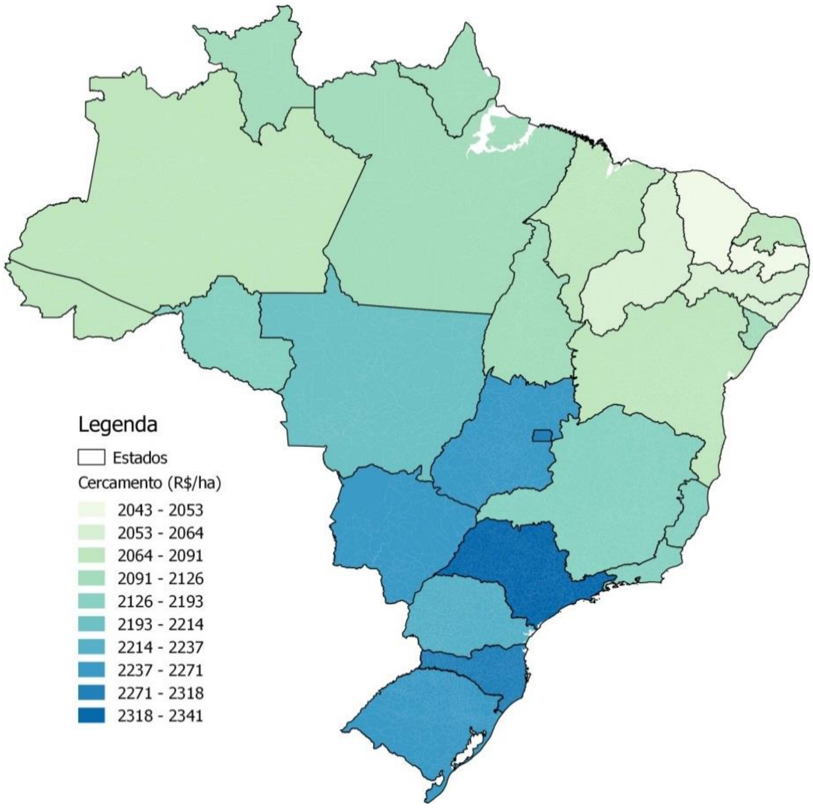
Figure 88: Dispersion plot for deforestation and remnants by municipalities, clasified using cluster analysis.

Source: cluster analysis

Annex 10: Fencing costs and reforestation costs results

It was possible to estimate fencing costs between R $ 2,043 and R $ 2,341 per hectare. The average value was R $ 2,185, and the data variability was low, highlighting the fact that more than 90% of Brazilian municipalities presented hedging costs between R $ 2,086 and R $ 2,284 per hectare.

Map 38 illustrates the spatial distribution of fencing costs, excluding transportation and project management costs. The highest costs are located in the South, Center West and in some areas in the Southeast, while the lowest values occur in the Northeast and North. This pattern of distribution reflects the differences in the value of the average monthly incomes of the labor force employed in the rural environment in each unit of the federation.



Map 38: Fencing costs per hectare (excluding input and administration costs), R $ / ha, 2013 prices

Source: own elaboration

Additionally, we calculated project value considering administration and transport the costs. The inclusion of these costs was done by applying a margin of 10% on the total project costs and 15% on the cost of the inputs, respectively. In this case, the results changed from R $ 2,650 to R $ 2,981 per hectare, with an average of R $ 2,808 / ha (an increase of 28.5% in relation to the cost of fencing). Distribution pattern of values remained the same, because a margin is applied to the previous result.by including input transport costs and project management costs,

Reforestation costs

Concerning the costs involved with the reintroduction of seedlings (or cost of replanting), the costs of land clearing (CL), settling costs (EC) and, finally, maintenance costs in the second and in the third year of the project, identified by CM2 and CM3, respectively.

Costs involved in replanting projects occur over three years, then, it is necessary to bring to present value expenses whose payment occurs at some period in the future (second or third years of the project). These costs were discounted at an *r* rate, assumed at 6%, in line with the rate chosen in for the opportunity cost of land.

Literature review on reforestation reveals that a number of factors have a preponderant role in determining replanting costs. Firstly, it is worth noting that projected costs depend on seedlings composition, according to their type (native and exotic) and their ecological group, see Table 62.

Table 62: Prices of seedlings, wholesale, retail and by successional class.

Type	Ecological group	Retail price (mean BRL$ 2013)	Wholsale price (mean, BRL$ 2013)	% of seedling mix	Weight price,BRL$ de 2013
Exotic	NA	75,88	3,55	15%	0,53
Native	Clímax	9,96	3,39	25%	0,85
	Pioneer	10,20	2,20	20%	0,44
	SecondaryInicial	9,85	2,47	15%	0,37
	Late Secondary	13,54	6,46	25%	1,62
Mean price by sedling		23,89	3,61	100%	3,81

Source: adapted from IBF (2015)

Table 62 shows a mix of species defined with different shares, relative to each ecological group. Total average cost per seedling is R $ 3,81, which is a high cost, compared to other costs reported in the literature review.

Another important factor is the difference between wholesale and retail prices. Wholesale purchase of seedlings can reduce costs between 50% and 90%. An alternative estimate for the mean price per seedling can be found in Silva et al. (2015). In it, the average price of seedlings was calculated at the regional level, based on information collected from 1.276 seedling nurseries in Brazil (Table 58).

Table 63: Cost of seedlings, wholesale and retail prices by region.

Region	Seedlings production cost (R$ de 2013)			Seedlings sale price (BRL$ 2013)					
				Retail			Wholsale		
	Mean	% SD	Number of green houses	Mean	% SD	Number of green houses	Mean	% SD	Number of green houses
North	1,57	109,12	18	3,34	55,09	19	2,23	65,92	16
Northeast	1,47	67,44	17	4,75	80,35	14	2,49	77,84	17
Southeast	1,21	74,18	64	2,62	72,70	67	1,80	73,41	65
South	1,64	161,55	28	8,42	178,67	26	2,20	121,75	25
Cente-	2,53	99,92	20	5,40	85,43	25	3,92	91,95	23
Total	**1,55**	**114,17**	**147**	**4,37**	**160,18**	**151**	**2,33**	**96,87**	**146**

Source: adapted from Silva et al. (2015)

IBF (2015) present significant divergences in the price of seedlings between the Brazilian regions, then, we used data from Silva et al. (2015). The justification for this choice lies in the attempt to capture an approximate interregional difference in the seedling market for reforestation.

There is no mention in Silva et al. (2015) on the composition of the seedlings by ecological group compared to IFB (2015); the authors only portray the average price reported by seedlings producers. These average sale prices obviously reflect a specific but unknown mix of seedlings used in forest recovery. We used average prices presented Silva et al. (2015) as a parameter for replanting costs estimation, then, it was assumed that the species composition presented in that study is representative for the whole country.

Input prices used in reforestation (fertilizers, formicides, etc.) were obtained from CONAB (2015), and adjusted for 2013 prices, using the implicit IBGE GDP deflator (Table 64)

Table 64: Prices of different reforestation inputs (R $ 2013).

State	FU	Glyphosate (BRL$/l)	Formicide Sulfuramide (BRL$/kg)	Fertilizer (BRL$/kg)	Triple phosphate (BRL$/kg)	Dolomite lime (BRL$/ha)
Acre	AC	20,82	9,05	1,13	0,68	0,07
Amazonas	AM	20,82	9,05	2,15	0,68	0,32
Amapá	AP	18,11	9,05	2,15	0,68	0,32
Maranhão	MA	18,11	9,05	1,25	0,71	0,09
Mato Grosso	MT	15,25	9,05	1,28	1,11	0,08
Para	PA	18,11	9,05	1,21	0,82	0,09
Rondônia	RO	20,82	9,05	2,15	0,68	0,32

Roraima	RR	20,82	9,05	2,15	0,68	0,32
Tocantins	TO	18,11	10,41	1,21	0,82	0,09

Source: CONAB (2015)

Inputs' price variation for forest recovery at the state level was considerable. For dolomitic limestone, prices per kilo showed differences of up to 448%, and for herbicides (glyphosate) the difference was up to 195%. These differences are explained by distance to production areas, quantities offered, exchange rate, seasonality of production and demand, among others.

Different cost structures presented in several studies, identify average quantities used in forest recovery according for different biomes (Table 65).

Table 65: Quantities of inputs per hectare, used in reforestation, for different Brazilian biomes.

Input quantities			Biome					
Fase	Service phase	Product	Amazonia	Mata Atlântic	Pampa	Pantanal	Caatinga	Cerrado
			$/ ha	$/ ha	$/ ha	$/ ha	$/ ha	$/ ha
Land cleanin		Motorrocade	20	20	20	20	20	20
		Round-up(l)	2,75	3,5	3,5	3,125	3,125	3,125
		Labor Round	12	12	12	12	12	12
Planting	Ant control	Labor (Hh)	3,453	11,996	11,996	11,107	11,107	11,107
		Formicide (I	0,839	2,916	2,916	2,7	2,7	2,7
	Manual swiv	Labor (Hh)	40	53,333	53,333	46,667	46,667	46,667
	Coving	Labor(Hh)	66,165	74,911	74,911	62,776	62,776	62,776
	Basic fertiliz	Labor (Hh)	11,579	17,592	17,592	14,086	14,086	14,086
		Fertilizer 4-1	175,75	230,833	230,833	90,706	90,706	90,706
		Manure (Kg)	0	0	0	0	0	0
		Rock phosph	56,24	242,327	242,327	123,698	123,698	123,698
		Micronutrien	0	0	0	0	0	0
		Lime (Kg)	144,115	374,85	374,85	133,4	133,4	133,4
		Liming Labo	8,271	9,8	9,8	7,847	7,847	7,847
	Planting	Labor (Hh)	40,869	59,405	59,405	47,566	47,566	47,566
		Seedlings	1406	1666	1666	1334	1334	1334
	Replanting	Labor (Hh)	1,659	2,454	2,454	1,969	1,969	1,969
		Seedlings	141	167	167	134	134	134
	Fertilization	Labor (Hh)	6,752	8	8	6,406	6,406	6,406
		Kg	70,3	83,3	83,3	66,7	66,7	66,7
Maintenance ye	Weed contro	Labor (Hh)	41,353	74,48	74,48	59,638	59,638	59,638
	Ant control	Labor (Hh)	13,498	15,994	15,994	12,806	12,806	12,806
		Formicide (k	2,812	3,332	3,332	2,668	2,668	2,668
	Weed contro	Labor (Hh)	41,353	74,48	74,48	59,638	59,638	59,638
Maintenance year 3	Weed contro	Labor (Hh)	41,353	74,48	74,48	59,638	59,638	59,638
	Weed contro	Labor (Hh)	41,353	74,48	74,48	59,638	59,638	59,638
Total		Labor year 2	210,747	269,492	269,492	230,425	230,425	230,425
		Labor year 3	389,656	583,405	583,405	481,782	481,782	481,782
		Total seedling	1547	1833	1833	1468	1468	1468

Source: own elaboration

In the absence of information on quantities and prices of inputs at the municipal level, it was assumed that the regional / state data are representative of all the municipalities that comprise each state.

Declivity is another important factor affecting replanting costs, because it determines the number of seedlings to be planted in each locality, to support superficial soils, avoiding erosion process (DEPRA et al., 2009). Accepting this proposal, we chose to work with seedling densities by slope degrees (Table 65). Seedling densities per hectare can range from 1.300 to 1.600, low density, and 2.200 to 2.500, in high density. Both scenarios will be presented in the next section.

Table 66: Number of seedlings per hectare for different types of slope, by biomes in Brazil

	Biome	
System	Amazon	Pantanal, Cerrado
Low density (declivity <25%)	1.406	1.334
High density (declivity > 25%)	2.500	2.224

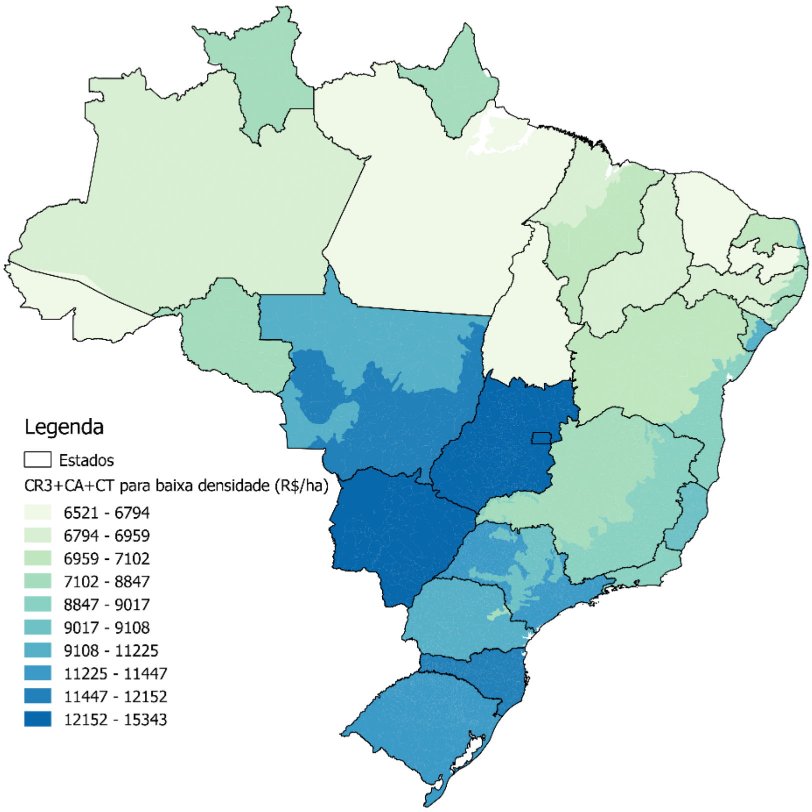
Source: based on Deprá et al. (2009); Plaster et al.(2008); Junior et al. (2008); TNC (2013); Silva et al. (2011); Silveira e Coelho (2008); MMA-IBAMA (2011)

In addition to input costs and seedlings cost, we consider: (i) labor costs, (ii) inputs' transportation costs to the planting site, and (iii) project management costs. Labor costs, reflect the same level as in fencing costs section. In addition, it was considered the scenario in which labor is required for three years; one year of establishment of the project, plus two years of maintenance (i.e.: weeds control at the base of the trees and ant combat).

Reforestation costs.

It can be noted from Map 39 that replanting costs for low-density forest restoration projects ranged from R $ 6.521 to R $ 15.343 per hectare, with an average cost of R $ 9.191 / ha. Half of the Brazilian municipalities had a replanting cost of less than R $ 9.016 per hectare, with a standard deviation of R $ 2.041. The highest costs occurred in the Pampa and Mata Atlântica, in addition to the central portion of the Brazilian Cerrado. This spatial distribution of costs largely reflected higher labor incomes in the central-west, south, and southeast regions, as well as greater quantities of inputs required for these biomes (see Table 65). Mato Grosso, Mato Grosso do Sul and Goiás states also stand out with highest costs due to higher seedling prices (Table 63) and associated costs with labour payments in reforestation projects. In these states worker average income was R $ 1.126, R $ 1.340 and R $ 1.348 reais per month, respectively, while the Brazilian average was R $ 849, for example.

If the lowest price (R $ 0,80) per seedling, found in the literature review, was used for all regions in the country, replanting cost would change, and also spatial distribution. In this case, the Mata Atlântica and Pampa biomes would present the highest average costs for replanting projects, reflecting the higher labor costs and equally higher quantities of inputs required in these biomes (Table 65).



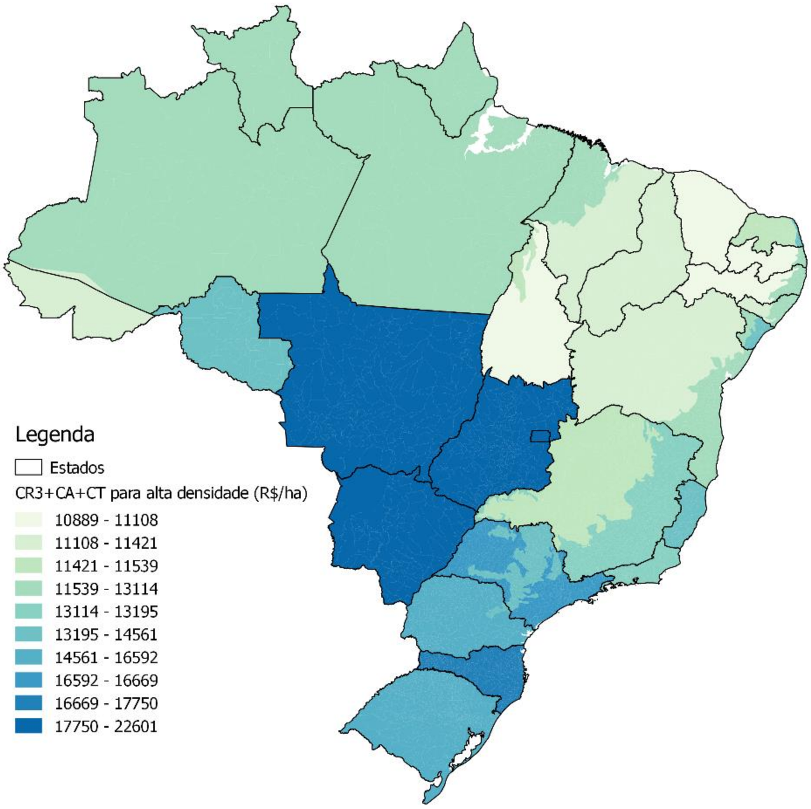
Map 39: Spatial distribution of replanting costs (R $ / ha) in Brazil for projects with low seedling density - (R $ 2013)

Source: own elaboration

From low to high-density seedlings scenario, replanting costs ranged from R $ 10.889 per hectare to R $ 22.601 (map 3), representing an average cost increase of 53,73% from R $ 9.191 per hectare to R $ 14.130.

The pattern of costs' spatial distribution has also undergone some significant changes, such as the relative increase in replanting projects in the Amazon biome. This is because the increase of seedlings from one scenario to another is greater in this biome than in the others. According to the literature review, while in the Amazon, the number of seedlings increase 70%, in Pampa and Atlantic Forest, it is 50%, and in other biomes, the variation is 66%.

Again, labour and seedling costs in reforestation projects imply that the central region is the most expensive. Pampa and Atlantic Forest biomes also presented high costs, especially for South and Southeast regions, but closer to the national average cost.



Map 40: Spatial distribution of replanting costs (R $ / ha) for high density of seedlings- (R $ 2013)

Source: own elaboration

Annex 11: REDD+ and co-benefits

Brown, Seymur and Pesket (2008) recall that UNFCCC, in its article 2 includes the objective of emissions reduction, while ensuring food production is not threatened and economic development proceeds in a sustainable way. They also recall that at COP 13 in Bali (2007), it was stated that REDD can produce co-benefits and may complement the aims and objectives of other relevant international conventions and agreements.

According to Ortega-P. et al (2010), the Bali Action Plan (2007) stated very clear that REDD+ is not only about carbon capture, but also carbon stocks, and sustainable forest management. This issue gives rise to the potential co-benefits that REDD+ projects can generate, and is finally the central topic for understanding the "+".

A REDD+ strategy can help to adaptation if it is viewed in the Ecosystem Based Adaptation framework (Ortega-P. et al., 2010) if elements like biodiversity conservation, use and sustainable management, ecosystems restoration and conservation, ecosystems services supply characterization and conservation, in order to allow communities adaptation to climate change. Ecosystem Based Adaptation was defined by Travers et al (2012) like the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels.

The broader dimension of co-benefits is related with (Brown, Seymur and Peskett 2008):

- Social co-benefits associated with pro-poor development
- Protection of human rights an improvement in forest governance
- Environmental co-benefits, particularly, enhanced biodiversity protection and soil and water quality and availability.

On the environmental co-benefits, Brown, Seymur and Peskett (2008) identified tropical forest conservation, avoids pitfalls of Afforestation/Reforestation schemes which tend to favour monocultures of exotic species, control soil erosion, and increase water quality an soil quality, avoid large scale climatic impacts, like rainfall reduction as a consequence of conversion of Amazon forests to pasture lands.

In addition, Minang and White (2010) identified co-benefits as non-carbon benefits, including employment, livelihood infrastructure and cultural services.

Stickler et al. (2009) have identified five key REDD+ interventions to reduce carbon emissions: a) reductions in deforestation, b) logging damage, c) forest fire, and d) increases in forest regeneration, d) increase on tree plantations. These interventions can generate substantial ecological co-benefits, and include the maintenance or restoration of (1) watershed functions, (2) local and regional climate regimes, (3) soils and biogeochemical processes, (4) water quality and aquatic habitat, and (5) terrestrial habitat.

Ortega-P et al (2010) recognize that benefits from forests are very complex; our knowledge of the relationship between biodiversity distribution and environmental services is not well developed yet. In addition, spatial and temporal scales are still not understood and the unevenness through time of environmental services implies additional complexities. Therefore, ecosystem services and co-benefits are difficult to quantify in per hectares' terms, so it is difficult to include explicitly in opportunity cost estimates (Pagiola and Busquets 2009).
Although co-benefits are difficult to quantify, they can be identified qualitatively, and incorporated in prioritization processes.

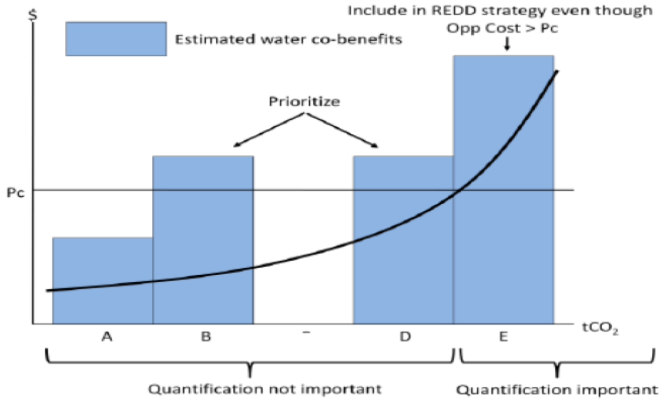


Figure 89: Co-benefits vs. opportunity costs

Source: Minang and White (2010).

Minang and White (2010) state that, quantification is important, when REDD+ costs exceed marginal benefits (price of carbon REDD credits). In a situation like activity E, where opportunity costs (marginal costs of activity E) are higher than the price of carbon emissions (marginal benefits), the inclusion of additional benefits of water may generate the inclusion of activity E, because expected net benefits are positive. When carbon costs are less than price of REDD+ credits there is no need to quantify, because the benefits will compensate costs of providing emissions reductions. Within activity A, in the figure above, opportunity costs of providing emission reductions are outweighed by carbon price of REDD+ credits, and additional water benefits will increment the producer surplus. Pagiola and Busquets (2009) show that in situations like these ones, opportunity costs can be negative, that is, the cost of reducing deforestation would be limited to the cost of implementing the measures necessary to increase the on-site benefits of forests.

Thinking on the difficulties of measuring co-benefits, the role of including co-benefits can be evaluated by the extent in which they will facilitate the success of a future REDD+ framework, or complicate and possible impede the signing of a global agreement (Parker et al 2008).

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