Economic evaluation of massive restoration in Brazil: how to achieve the iNDC-Brazil target

Andrea Lucchesi*

School of Arts, Sciences and Humanities,
University of São Paulo, Brazil
Email: andrea.lucchesi@usp.br
*Corresponding author

Paula Carvalho Pereda,
Maria Alice Móz Christofoletti and
Keyi Ando Ussami

Department of Economics,
University of São Paulo, Brazil
Email: pereda@usp.br
Email: maria.christofoletti@usp.br
Email: keyi.ussami@usp.br

Eduardo Gusson and Girlei Costa da Cunha

Biodendro Forest Consulting, Brazil
Email: eduardo.gusson@biodendro.com.br
Email: girlei.cunha@biodendro.com.br

Abstract: The Brazilian Government has established a target to restore 12 million hectares of the country's forest area by 2030. In this study, we address the economic and financial feasibility of this massive restoration, as well as job creation and government receivables, by applying a traditional valuation method and assumptions from the environmental literature. Conservative scenarios, based on an agricultural producer perspective, indicate that the recovery is economically unviable: the net present value is negative, and though the internal rate of return is positive, it is lower than the cost of capital. However, sensitivity analysis suggests that it may become feasible when considered as an outsourced business and a market for forest carbon capture is included. In terms of public policy, there is still room for creating instruments to improve its feasibility, since we have not addressed other positive externalities and also the sale of non-timber forest products.

Keywords: ecological restoration; forest restoration; forest economics; intended nationally determined contribution; UNFCCC; forest carbon capture; Brazil.

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Biographical notes: Andrea Lucchesi is a Professor at the School of Arts, Sciences and Humanities of the University of São Paulo (EACH/USP) in the area of economics and quantitative methods. She completed her PhD in Economics from the University of São Paulo, with a one-year interchange at the University of Birmingham, UK. Her main areas of research are quantitative methods applied to subjects related to: natural resource and environmental economics, public policy evaluation, innovation and labour market. Since 2016, she works as a researcher in a research project on innovation and productivity in Brazil in association with Harvard Business School and Lemann Foundation. She is a member of the European Association of Environmental and Resource Economists (EAERE).

Paula Carvalho Pereda is an Associate Professor at the Department of Economics of the University of São Paulo, Brazil. She completed her PhD in Sciences from the University of São Paulo, and Master's in Economic Theory from the same university. She worked as an IDB invited consultant from 2010–2013 and was a Full Professor and Academic Coordinator of the FAAP. She is a researcher at the Institute of Economic Research (FIPE). Her research focus is on applied microeconomic topics and she has ten years of professional experience in the area of economic and statistical modelling. She is a part of the Center for Regional Studies of USP (NEREUS) and a member of the Econometric Society.

Maria Alice Móz Christofoletti is a PhD student in Economics at the University of Sao Paulo, Brazil. She received her Bachelor's in Economics and Master's in Applied Economics, both from the University of Sao Paulo. She has more than five years of experience in economic/econometric analysis, mainly in agriculture and environmental issues and received, in 2010, the BM&F Prize for Agroindustrial Development, from BM&FBOVESPA Stock Exchange. Since 2017, she works as an Evaluation Analyst at the FAO Office of Evaluation and a member of the Regional and Urban Economics Lab of USP (NEREUS).

Keyi Ando Ussami is a PhD student in the Department of Economics at the University of Sao Paulo (USP) and contributes to its Regional and Urban Economics Lab (NEREUS). She received her Bachelor's in Economics and in Biology and Master's in Biological Oceanography, all from the same university. She worked as an environmental analyst in the field of water resources and geoprocessing for seven years, getting involved in projects all around Brazil. Her recent research area is related to input-output analysis, water footprint, deforestation and forest transition. She is interested in water resources, land use and environmental economics.

Eduardo Gusson is a partner in Biodendro Forestry Consultancy and a Guest-Researcher of the Center for Culture and Extension Support in Education and Environmental Conservation (NACE-PTECA) at the University of São Paulo, since 2001. He is a Forest Engineer, MSc in Agroecosystem Ecology, and PhD in Forest Resources from the University of São Paulo. He has 18 years of experience with conservation and biodiversity management, conducting projects in forest restoration, native tree species seed and seedlings production, planting and management of native and exotic forests aiming economic exploitation, monitoring and estimating tropical forest carbon stocks, community forest management planning, socio-environmental programs development and scientific research and communication.

Girlei Costa da Cunha obtained his degree in Forest Engineering from the Federal University of Santa Maria and Masters in Forest Resources from the University of São Paulo. He has experience in the area of forest resources and forestry, with emphasis on nature conservation and rural development, working on the following topics: environmental zoning, phytosociology, forest succession, ecological restoration, nutrient cycling and ecology of native tree species.

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1 Introduction

In 2010, the estimated forest degradation worldwide was approximately 2 billion hectares (ha) (Minnemayer et al., 2011). Forest fragmentation and degradation lead to biodiversity loss, climate change and ecosystem service depletion (Lima et al., 2015; Magnago et al., 2014; Millenium Ecosystem Assessment, 2005).

In September 2015, the Brazilian government published the intended Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (iNDC-Br 2015) (Federative Republic of Brazil, 2015). The iNDC-Br established targets related to land use, renewable energy and clean technologies to contribute to the goal of the Intergovernmental Panel on Climate Change (IPCC, 2014) of containing the global temperature increase to 2°C by 2100. Among these iNDC-Br targets,[1] the Brazilian government has committed to restoring and reforesting 12 million hectares (Mha) of forests by 2030, for multiple purposes. In December 2015, this commitment was further strengthened during the Climate Conference (COP 21) in Paris. According to the Society for Ecological Restoration, the term restoration is related to the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. In turn, the term reforestation is more general: one can reforest with any tree species, but restoration requires thoughtful consideration of the past and future states of biodiversity and the ecosystem.

In addition, the Brazilian Forest Code (2012) determines that rural landowners must preserve a portion of their properties for environmental purposes. This land is called legal reserve (LR) areas. Unfortunately, according to Soares-Filho et al. (2014), Brazil has an LR deficit of approximately 16 Mha. According to the Forest Code (FC), landowners with an LR deficit must recover it by 2032 and the restoration of the LR areas can include sustainable management measures.

Large-scale forest restoration, such as proposed by the Brazilian government, is challenging in both technical and economic terms. On the technical side, there are several possible methods and models that can be used and different biomes to consider, complicated by the absence of past experiences in large areas. On the economic side, many challenges arise, from the demand forecast for timber and non-timber forest products (assuming the possibility of economic exploitation of the recovered area) to the economic feasibility of reforestation.

To contribute to this debate, this study aims to produce accurate estimates of the value of the large-scale forest restoration proposed. This massive restoration will demand large investments. Moreover, the planted forests will generate a long-term cash inflow and a short-term cash outflow. Due to its lack of economic attractiveness, the market economic equilibrium suggests low provision of the restoration product. However, since reforestation generates many positive externalities (e.g., carbon sequestration, watershed protection, biodiversity preservation), the economic literature indicates that the market equilibrium is distortive and does not reflect the socially optimal provision of reforestation for the economy (Mas-Colell et al., 1995; Varian, 1992).

This paper evaluates the economic feasibility and investment required for the restoration of 12 Mha of forest in Brazil up to 2030 by considering timber market products (non-timber products are not included due to their incipient marketing) using different restoration models. We allocate this forest restoration to LR deficit areas[2] in the Atlantic Forest and Amazon biomes, considering the sustainable management of forest resources, in time horizons of 35 and 50 years. The economic analysis is developed from the producer perspective and explores the impacts on jobs and tax collection. We also estimate the number of direct jobs required for the restoration and the amount of carbon uptake of this activity. The carbon sequestration has an established market[3] for trading and is key to the discussion of climate risk mitigation in the future (Olschewski and Benítez, 2010; Torres et al., 2010).

After this introduction, the paper is organised as follows: Section 2 discusses the ecological restoration practices which are the basis of the restoration models considered in this paper. Section 3 describes the methods and assumptions for the economic evaluation of different LR restoration scenarios. Section 4 presents the results of the baseline model and the sensitivity analysis, and Section 5 summarises the results and discusses the contributions and limitations of the study.

2 Ecological restoration practices and the Brazilian Forest Code

According to the International Tropical Timber Organization (2002), 350 Mha of tropical forest areas have been so severely damaged that forests will not grow back spontaneously, and 500 Mha have forest cover that is either degraded or has re-grown after initial deforestation. Approximately 80% of the world's terrestrial species are inhabitants of natural tropical forests, making these forests fundamental for the conservation of biodiversity (ITTO/IUCN, 2009). Moreover, IPCC (2014) estimates show that the Agriculture, Forestry and Other Land Use (AFOLU) sector accounts for about a quarter (~10–12 $GtCO_2eq$/year) of net anthropogenic greenhouse gas (GHG) emissions, mainly from deforestation, agricultural emissions from soil and nutrient management, and livestock.

Restoration models can be defined as systematic designs or arrangements for forming a new ecosystem and its ecological and economic sustainability. Some of the guiding elements for designing a restoration model include ecological succession concepts, abiotic environment characteristics, species' economic potential, local infrastructure, and domestic markets. Despite the progress achieved by researchers, the restoration models remain restricted to the scope of the situation to be recovered. The models have limited applicability in extensive areas due to their high costs of implementation and maintenance, demonstrating the need for less expensive and more accessible technologies (Albuquerque et al., 2010).

Wortley et al. (2013) noted the importance of the socio-economic attributes of restoration, which they believed should be the future focus of empirical research on quantifying ecosystem services. Socio-economic outcomes are essential for understanding the full benefits and costs of ecological restoration and to support its use in natural resource management. According to the Brazilian Forest Code, the LR areas serve the function of forest production associated with biodiversity conservation while promoting other ecosystem services (such as water conservation, mitigation of climate effects and soil protection).

The FC establishes standards for the protection, restoration and sustainable use of native vegetation and for legally protected areas within private properties, such as permanent preservation areas (PPAs) and LRs. PPAs include riparian areas, springs, hilltops, areas at high altitudes and steep slopes. LR areas consist of a percentage of each rural property that has to be maintained as native vegetation to ensure environmental preservation. In general, the LR percentage is 20% (including Atlantic Forest areas). For rural properties located in the legal Amazon[4] municipalities,[5] this percentage increases and varies according to the area's native vegetation: 80% for properties located in forest areas, 35% for properties located in savannah and 20% for those established in open fields.

There are two alternatives for owners of rural properties that lack the required minimum LR percentage:

1 Restoring the area through natural regeneration or reforestation, which has to be done with native species or with native and exotic species intercropped in an agroforestry system, as long as the exotic ones do not exceed 50% of the total reforestation area.

2 Compensating all or part of the LR area, which can be achieved by acquiring an environmental reserve quota (a tradeable land use permit, in which one quota is equivalent to one hectare of LR surplus in another rural property), leasing an area with native forest on another rural property that exceeds the required LR, or donating to the state an area within a public conservation unit,[6] pending the regularisation of land tenure. These areas must be in the same biome as the LR area to be offset, and if they are located outside the state, they must be in areas identified as priority by the federal and state governments.

In addition, the FC establishes that small and family-owned farms are not required to recompose their respective LR if they do not have the minimum percentage of native vegetation outlined by law. Rural properties that have agroforestry activities and are smaller than four fiscal modules (FMs)[7] (one FM varies from 5 to 100 ha, depending on the municipality) are considered by the FC to be small farms or rural family possessions.

The Brazilian iNDC statement on the restoration and reforestation of 12 Mha is not restricted to LR areas: it includes protected areas such as PPAs and areas of exotic forestry (eucalyptus, pine, among others). According to Soares-Filho et al. (2014), Brazil has a PPA deficit of approximately 5 Mha and its restoration would definitely enhance the environmental characteristics of rural properties. However, according to the FC, these areas cannot be used for economic purposes (even with sustainable management procedures), so they were excluded from the analysis in this paper. Exotic forestry was also excluded due to its low contribution to environmental improvement of rural areas.

3 Methodology

3.1 General assumptions related to the proposed restoration

The restoration models used in this study were chosen so that the ecosystem recovery process could be triggered or accelerated, respecting the principles of biodiversity conservation and biome characteristics (climate, soil, and species). Therefore, wood accumulation volume is obtained from data on native forests planted exclusively for restoration purposes, that is, it does not consider intensive forestry practices (usually required of planted forests for economic purposes).

The restoration models are built following the rationale of secondary succession processes, in which pioneer species (fast-growing) are initially planted. The timber obtained from pioneer species is considered less valuable, but serves as a guide for non-pioneer species (moderate or slow-growing), which produce more valuable timber in the long-term. The spatial arrangement between species, considering different management methods and harvesting times so as to provide income in different periods, was also formulated following this rationale.

We also consider that the expected revenue of the project is related only to the sale of timber products, specifically based on standing timber prices, presupposing the existence of sawmills within a reasonable distance from the restored areas and appropriate roads interconnecting them. We use the timber price variation to verify the sensitivity of the results. The possibility of additional revenue derived from non-timber forest products (NTFPs – such as resins, fibres, nuts, and native fruits) is not considered because NTFP production is still a complementary and often unstable activity.

Moreover, we consider the restoration project from the perspective of medium and large rural producers, who are obligated to recompose their LR areas. Following several studies of LR areas (The Nature Conservancy, 2013), we consider that these areas have an opportunity cost close to zero, and we do not include this cost in the analysis for two reasons. First, the literature argues that these areas have low profitability and thus represent a liability to their owners. Second, we have limited information on the location and value of these areas, which could be improved with new data (related to Rural Environmental Registry – CAR) that has been processed by the federal government.[8]

3.2 Location of forest restoration projects

In order to estimate the location of the areas to be restored, we use the 2006 Agricultural Census conducted by the Instituto Brasileiro de Geografia e Estatística (IBGE, 2006) and estimate, for all Brazilian municipalities, the total area of rural properties larger than four FMs (considered medium and large farms) as well as the total forest area within these properties. The biome of each municipality is defined by overlapping spatial data from IBGE and the biomes categorised by the Ministry of the Environment (MMA). The LR percentage required in each municipality is obtained by a weighted average of the percentages described in the FC and the respective biomes that compose each municipality.

These calculations reveal an LR deficit of 2.9 Mha (11.7% of the total) in the Atlantic Forest, 15.2 Mha (61.5% of the total) in the Amazon, 4.4 Mha (17.8% of the total) in Cerrado (Brazilian savannah) and 2.2 Mha (8.9% of the total) in other biomes (Caatinga, Pampa and Pantanal). We focus our study on the Atlantic Forest (ATF) and Amazon (AMZ) biomes,[9] allocating 2.9 Mha to the Atlantic Forest and 9.1 Mha to the Amazon (therefore totalling 12 Mha following the iNDC-Br target), because:

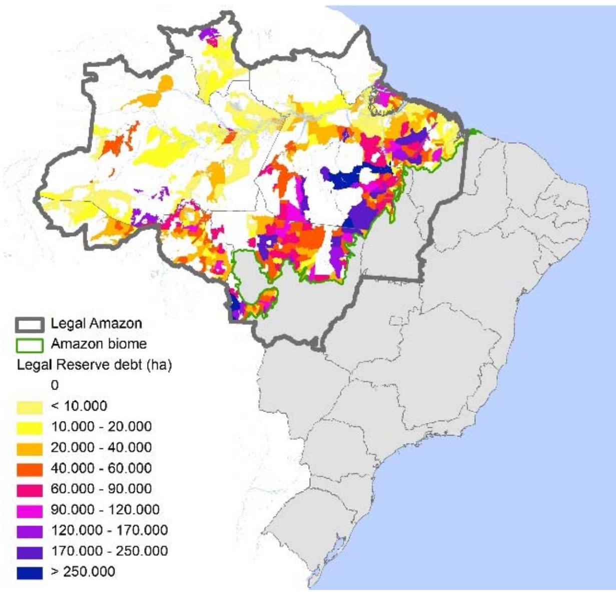
1 These biomes account for 73.2% of the total LR deficit of Brazilian rural properties.

2 Reforestation projects in the Atlantic Forest and Amazon areas are more developed than in the other biomes (for instance, Cerrado also presents a significant portion of LR deficit, however reforestation projects are still in their early stages of development).

3 The total LR deficit located in the Atlantic Forest (2.9 Mha) was chosen to be recovered also due to its proximity to suppliers and consumers.

The territorial distribution of the estimated LR deficit is presented in Figure 1.

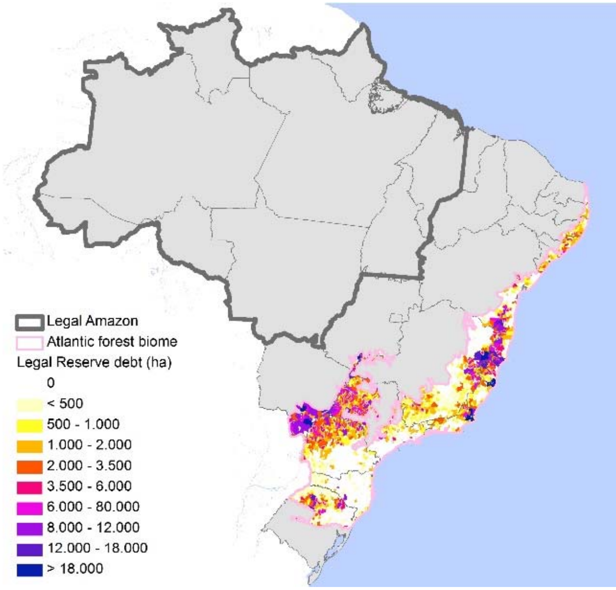
Figure 1 Location of the LR deficit in the, (a) Amazon (b) Atlantic Forest biomes (see online version for colours)



(a)

Source: Prepared by the authors based on the Agricultural Census 2006 (IBGE)

Figure 1 Location of the LR deficit in the, (a) Amazon (b) Atlantic Forest biomes (continued) (see online version for colours)



(b)

Source: Prepared by the authors based on the Agricultural Census 2006 (IBGE)

3.3 Models

The forest restoration models adopted in this study are based on the methods and techniques for vegetation recovery presented in the preliminary version of the National Native Vegetation Recovery Plan (Portuguese acronym: PLANAVEG) (Ministério do Meio Ambiente, 2014), conducted by the Brazilian Ministry of Environment and considered as the government's official plan. Scenario 'A' presented in PLANAVEG (one of the three scenarios presented) is chosen to define the share of each restoration model concerning the 12 Mha recovery (Table 1).

Table 1 Forest restoration models' share (based on PLANAVEGs scenario 'A')

Model no.	*Description*	*Share*
1	Passive restoration[1]	40%
2	Guided growing + enrichment	15%
3	Densification + enrichment	15%
4	Total area – sowing seeds	7.5%
5	Total area – native species seedlings	7.5%
6	Total area – seedlings – 25% eucalyptus	7.5%
7	Total area – seedlings – 50% eucalyptus	7.5%

Note: [1]According to PLANAVEG, it is assumed that half of the area destined to passive restoration would be unfenced.

Source: Based on PLANAVEG

Table 2 Summary of restoration models' characteristics

Model no.	*No. of seedlings per ha*	*% of fast-growing species*	*% of moderate-growing species*	*% of slow-growing species*
1	- (passive restoration)	-	-	-
2	417	-	50% (native) *21 years*	50% (native) *35 years*
3	833	50% (native) *14 years*	25% (native) *21 years*	25% (native) *35 years*
4	- (direct sowing)	40% (native) *7 years*	40% (native) *14 and 21 years*	20% (native) *35 years*
5	1,667	50% (native) *7 and 14 years*	25% (native) *21 years*	25% (native) *35 years*
6	1,667	50% (25% eucalyptus, 25% native) *7 and 14 years*	25% (native) *21 years*	25% (native) *35 years*
7	1,667	50% (eucalyptus) *7 and 14 years*	25% (native) *21 years*	25% (native) *35 years*

Note: Species composition in parentheses and age for harvesting in italics.

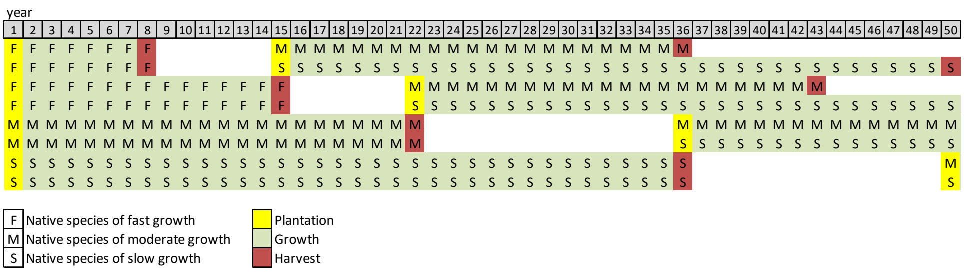
The seven models considered in scenario 'A' are summarised in Table 2 and can be briefly described as follows:

- Model 1 (passive restoration) has a single intervention: area isolation. This isolation can be performed by implementing a fence and fire breaks to prevent the action of factors that may be harmful to the natural regeneration of the system, such as cattle and fire. As there is no planting activity, there is no timber harvested in this model. Based on PLANAVEG, half of the area destined to passive restoration is kept without fencing.
- Model 2 (guided growing + enrichment) proposes planting 417 native seedlings per ha (conventional 3 × 2 metre planting) – 50% moderate-growing species and 50% slow-growing species. The timber harvest should occur at age 21 for the first group and age 35 for the second group.
- In turn, Model 3 (densification + enrichment) has 833 native seedlings per ha – half of them fast-growing species, 25% moderate-growing and 25% slow-growing. The timber harvest must occur at age 14 for all the fast-growing species, age 21 for all moderate-growing ones and age 35 for the slow-growing species.

- Model 4 (sowing seeds) establishes the use of cultivation methods through directly sowing seeds of different groups of species. Therefore, the planting process must be performed in proportions of 40%, 40% and 20% with fast-, moderate- and slow-growing species, respectively. All fast-growing trees are harvested at the age of 7 years, 50% of the moderate-growing trees are harvested at age 14, and the remainder are harvested at age 21. All slow-growing trees should be harvested at age 35.
- In Model 5 (native species seedlings), 50% of the trees are fast-growing species, 25% are moderate-growing ones, and 25% are slow-growing trees. In contrast to model 4, half of the pioneer trees should be harvested at age 7, and the other half should be felled at age 14. All moderate- and slow-growing trees should be cut at ages 21 and 35, respectively.
- In turn, Model 6 (seedlings – 25% eucalyptus) proposes the use of eucalyptus as a pioneer species to shade other trees during establishment of the system. Therefore, planting is equally distributed between seedlings of eucalyptus and native rapid-, moderate- and slow-growing species (417 seedlings/ha per group, or 25% of the total area per group). The eucalyptus harvest is performed at age 7, and fast-growing native species are cut at the age of 14. For other trees, the period and harvest intensity are the same as in model 5.
- Model 7 (seedlings – 50% eucalyptus) differs from model 6 because there is a maximum amount of exotic trees that can legally be used in the system. In this model, the use of eucalyptus reaches 50% of the total area. Thus, it is proposed to harvest eucalyptus trees in two cycles, i.e., at ages 7 and 14. Subsequently, the exploitation of moderate-growing species should occur at age 21, ending with the exploitation of slow-growing species at age 35. In all harvest cycles, 25% of the planted trees are cut.

Therefore, the models used in this study range from less expensive methods – such as passive restoration – to total planting methods with a great diversity of species, including the use of exotic species.

Figure 2 Example of tree replacement over 50 years in model 5 (planting in year 1) (see online version for colours)



Source: Prepared by the authors based on PLANAVEG

The logic of sustainable forest management and LR exploitation requires the replacement of tree inventories to maintain the timber product supply. Thus, the first reintroduction of new trees in the system should occur when the total harvest represents 50% of all trees initially introduced. At this point, the area will have similar conditions as model 2 in terms of tree density. Thus, models 3 to 7 present the replanting of 417 trees/ha, which corresponds to 25% of the total amount of plants used in conventional planting. Figure 2 indicates the timber management with the replacement of trees in LR areas.

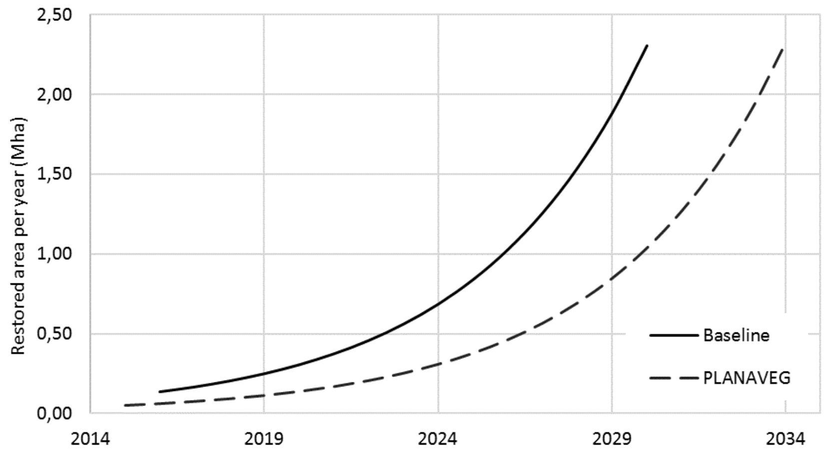
3.4 Implementation schedule

The implementation schedule is based on PLANAVEGs definitions adapted to Brazilian iNDC and considers:

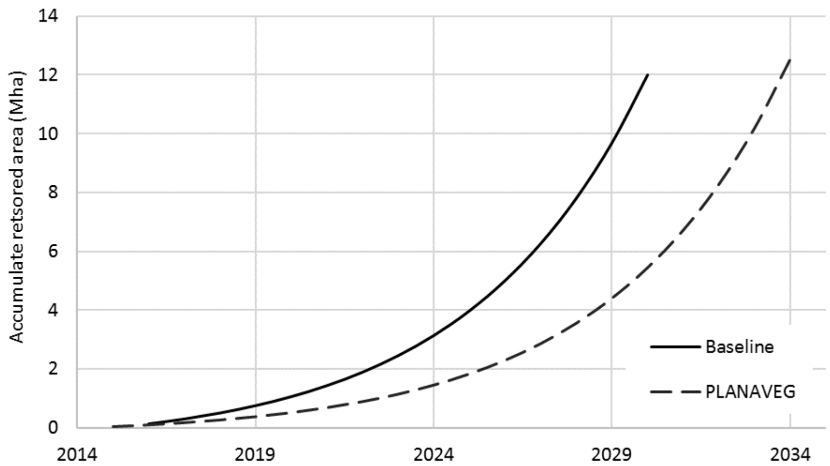
a the recovery of 12 Mha in 15 years, starting in 2016 (with 0.136 Mha) and ending in 2030 (total of 12 Mha)

b average annual growth rate of 22.4%.

Figure 3 Implementation schedule: baseline and PLANAVEG, (a) restored area per year (b) accumulated restored area



(a)



(b)

In this sense, the baseline schedule adopted in this study differs from PLANAVEG since we have adapted PLANAVEGs schedule to meet the Brazilian iNDC targets.[10] Figure 3 shows the adopted implementation schedule (baseline) in contrast to PLANAVEG initial definitions.

It is worth noting that 2030 marks the end of new restoration areas, but the following years require maintenance measures to ensure continued harvest revenues.

3.5 Financial and economic analysis

Among the main valuation methods, we adopt the discounted cash flow (DCF) approach, which involves free cash flow forecasting of the forest restoration models over time.

Due to the restoration models adopted in this study, two different time horizons are considered:

1 35 years and 50 years, both starting in 2016 (year 1)

2 ending in 2050 (year 35) or ending in 2065 (year 50).

In 2030 (year 15), the last hectares will be restored, so the total restored area will reach 12 Mha. In 2050 (year 35), all moderate-growing trees planted in 2030 will be approximately 20 years old and will be harvested. In 2065 (year 50), all slow-growing trees planted in 2030 (at age 35) will be cut. In this 50-year period, trees are replanted and partially cut because not all trees reach maturity in the forecast horizon.

The financial and economic criteria for analysing the viability of the restoration models are the internal rate of return (IRR) and the net present value (NPV).

3.5.1 Cash flow components

The projected cash flows are composed of the revenues and costs of the different forest restoration models (presented in Subsection 3.2.2) based on 2015 prices.

The expected revenues are obtained based on the estimates of the mean annual increment (MAI) of native forests planted in the Atlantic Forest and Amazon biomes (detailed in Table 3) and on 2015 prices for timber products. In the Atlantic Forest biome, the MAI parameters are estimated based on a primary survey of 4,200 trees of different ages – ranging from 2–3 years up to 30 years – from reforestation projects with mixed native species, located on the banks of hydroelectric reservoirs in the state of São Paulo, owned by the São Paulo electric utility (CESP). Some of them are under concession by AES Tiete (Tietê and Grande Rivers) and Duke Energy (Paranapanema River). Secondary data from Carvalho (2008), Coradin et al. (2011), Hess and Schneider (2010), Nunes (2013) and Ré (2011) were also used to calibrate the estimates. For native species of the Amazon region, the MAI parameters were based on secondary data collected from Arco-Verde and Schwengber (2003), Brienza et al. (2008), Carvalho (2003), Souza et al. (2008) and Tonini et al. (2008).

Due to the wide use of eucalyptus in Brazilian forestry and the possibility of its use in LR reforestation projects, data for eucalyptus are also compiled (Table 3). Price estimates for reforested wood (standing timber) are based on data from the Center for Advanced Applied Economic Studies (CEPEA) and the Information Bulletin of the Brazilian Agriculture and Livestock Confederation together with Federal University of Viçosa (CNA/UFV) and include only the costs related to the management and forest harvesting.

Similarly, the costs are estimated according to the biome and restoration technique. Operating costs include labour (wages of field hands, tractor drivers and supervisors), materials (inputs such as seedlings, fertilisers, pesticides and fencing), machinery and equipment, technical assistance (covering the pay of technicians and forestry engineers) and insurance (high level of coverage). Wages are obtained by the average wage of the Brazilian states that belong to each biome (weighted by LR debt), based on data from the General Register of Hiring and Dismissal (CAGED/RAIS), for 2014–2015 [collected by the Ministério do Trabalho (n.d.)]. Machinery and equipment costs are estimated based on operating costs of farm tractors, available from the Office to Coordinate Technical Assistance (CATI), São Paulo State Agriculture and Supply Secretariat. The regionalisation of those costs is based on diesel prices – the most important input for machinery costs – in the states of Pará (concerning the Amazon biome) and São Paulo (related to the Atlantic Forest biome) in November 2015.

Table 3 Assumptions – expected revenues in forest recovery models

Species group (defined by the growth rate)	*Cutting cycles (years)*			
	1st cutting cycle (7–8 years)	*2nd cutting cycle (13–15 years)*	*3rd cutting (20–22 years)*	*4th cutting cycle (33–38 years)*
Fast growth	DBH 10–15	DBH 18–21		
	US$21	US$36		
	MAI 0.105 (AMZ)	MAI 0.252 (AMZ)		
	MAI 0.095 (ATF)	MAI 0.210 (ATF)		
Fast growth (eucalyptus)	DBH 13–18	DBH 20–30	DBH 30–40	DBH 50–80
	US$21	US$30	US$54	US$75
	MAI 0.161	MAI 0.364	MAI 0.609	
Moderate growth	DBH 7–10	DBH 12–15	DBH 18–22	DBH 28–33
		US$36	US$120	US$150
		MAI 0.147	MAI 0.252	MAI 0.473
Moderate growth (exotic species)	DBH 10–15	DBH 16–20	DBH 22–30	DBH 35–45
		US$60	US$90	US$150
		MAI 0.175	MAI 0.305	MAI 0.560
Slow growth			DBH 17–22	DBH 30–40
			US$180	US$270
			MAI 0.137	MAI 0.263

Notes: Diameter at breast height (DBH). It presupposes the existence of a standing timber consumer market within a distance of less than 200 km from the recovered area. Mean annual increment (MAI); AMZ = Amazon; ATF = Atlantic Forest. Values that are not discriminated are equal in both biomes. Exchange rate: R$3.33/US$. 2015 prices.

Additionally, based on the projection of the area to be restored, the maximum amount of labour demanded in the reforestation project is estimated. Table 4 presents the final costs in each biome.

Table 4 Assumptions: implementation costs of forest recovery models

Costs items		*Atlantic Forest (ATF)*	*Amazon (AMZ)*
Labour (US$/MH)[1]	Field hands	5.03	5.01
	Tractor drivers	6.58	6.31
	Supervisors	9.55	11.15
	Technicians	8.70	8.96
	Forestry engineers	22.45	17.41
Diesel (US$/L)[2] and machinery (US$/MH)[3]	Diesel	0.80	0.96
	Operating cost (without labour)	33.71	37.76
Insurance (%)[4]	High level of cover	0.42%	0.80%

Notes: [1]cost corresponds to outsourcing labour, incorporating 18% for taxes, 10% for profit and 10% for administrative costs. The monthly costs of labour are converted into man-hours (MH) considering an 8-hour working day (22 working days per month). Weighted average wage for each biome, using the state's average wage from September 2014 to August 2015 and the state's share of LR deficit.
[2], [3]machinery costs are measured considering that the equipment would be rented, resulting in an increase of 30% compared to the cost of owning equipment.
[4]insurance costs are calculated based on 2.1% of the value at risk, which corresponds to total operating costs and investments. In both biomes, a 60% grant offered by the federal government is considered. In the Atlantic Forest, a 20% grant offered by the states of São Paulo and Paraná for this type of insurance is also considered. According to the Brazilian Classification of Occupations (CBO), field hands are classified as workers involved in general agricultural activity (code 6210), tractor drivers as workers in forest mechanisation (code 6420), supervisors as supervisors in forestry and fishery activities (code 6320), technicians as foresters (code 3212) and forestry engineers as environmental engineers (code 2221).

Source: General Register of Hiring and Dismissal (Ministério do Trabalho, n.d.)[1], Savastano and Atarassi (n.d.)[2],[3] and Prata (2012)[4]. Exchange rate: R$3.33/US$. 2015 prices

The costs are expected to be incurred in four stages:

1 pre-implementation (lasting 3 months)

2 implementation (lasting 3 months followed by a period of 3 months without any expenditure)

3 plantation maintenance (lasting 24 months followed by a period of 12 months without any expenditure)

4 forest management (lasting approximately 30 months).

Each of the four stages of the restoration project is set with different operational coefficients for labour and machinery and different amounts of material (fencing, fertilisers, seedlings and pesticides).[11]

As this study considers the restoration project from the perspective of medium and large rural producers, these costs correspond to outsourcing/rental expenses incurred with labour and machinery. The total operating costs are equivalent to the initial restoration and replanting. In turn, non-operating costs related to insurance and costs incurred in fencing are allocated as investments. Additionally, direct taxes (contribution to the social integration program – PIS and contribution to finance social security – COFINS) are calculated based on gross revenue, and corporate income tax and social contribution on net profit are calculated based on net income.

3.6 Carbon capture estimates

Carbon capture estimates are performed for each biome and restoration model, considering the carbon contained in every carbon pool within a forest (i.e., above-ground biomass, below-ground biomass, deadwood, litter and soil organic carbon). Despite the fact that a significant part of the carbon is kept in the soil after harvesting, we opted to use a conservative approach and assume that 100% of the captured carbon would be released back to the atmosphere.

In the passive restoration model (model 1), the main assumption is that after 25 years the restored area will withhold as much carbon as natural forests by adjusting a logarithmic growth curve. The period of 25 years is a conservative approach, since Suganuma (2013) showed that after 13 years, restored riparian forests (by planting) from seasonally semi-deciduous forest biomass achieved the reference values for native riparian forests biomass. The standards for natural forest carbon stocks were obtained from the Brazilian National System of Forest Information (SNIF), which are continuously updated and follows recommendations from the United Nations Food and Agriculture Organization (FAO). The most recent estimates, based on data from 50 published works from the available literature until 2014, are that the Amazon and Atlantic Forest present 200.5 tC/ha and 116.8 tC/ha of natural forest carbon stocks, respectively.

For the remaining models (models 2 to 7), we estimate the amount of carbon capture per tree per year to quantify carbon capture and release over time, considering the implementation schedule as well as the harvesting and the replacement of trees in the different models (Table 5). All results are converted into CO_2e by multiplying them by 44/12, which is the ratio of molecular weights of carbon dioxide and carbon.

Table 5 Estimated carbon capture per tree per year (models 2 to 7)

Species	*Carbon capture (tC.tree^{-1}.year^{-1})*
Eucalyptus[1]	0.00857
Fast growing[2]	0.00476
Moderate growing[2]	0.00336
Slow growing[2]	0.00264

Source: [1]Maestri et al. (2004), [2]Average from the data presented by Finco and Rezende (2005) from Instituto Ecológica on estimates for 34 native species

3.7 Scenarios – baseline and sensitivity analysis

The baseline scenario is built based on the forest restoration models described in Subsections 3.1 to 3.6. Briefly, the baseline model intends to restore 12 Mha in 15 years (from 2016 to 2030), with an implementation schedule that grows 22.4% per year starting with approximately 136,000 ha. In this scenario, the restoration will be distributed over two Brazilian biomes: 2.9 Mha will be reforested in the Atlantic Forest biome and

9.1 Mha in the Amazon biome. The share of the seven different restoration models is based on PLANAVEGs scenario ‘A’,[12] which determines that 40% is destined to the passive restoration model (same share for both biomes). Fencing costs (50% of total model 1 area) are considered as investments.

The sensitivity analysis allows the evaluation of the financial and economic effects when certain assumptions are relaxed ceteris paribus. We analyse 13 alternative scenarios:

1 Different restoration model share (increases passive restoration model share to 50% and decreases total planting model share to 50%), based on PLANAVEGs scenario ‘B’.[13]

2 Different restoration model share (increases passive restoration model share to 60% and decreases total planting model share to 40%), based on PLANAVEGs scenario ‘C’.[14]

3 Different implementation schedule: exponential curve starting planting with 50,000 ha (the same starting point as PLANAVEG, instead of 136.000 ha) and a higher growth rate to achieve 12 Mha by 2030 (approximately 34.2% per year).

4 Different implementation schedule: increasing growth rates in the first years after planting and decreasing growth rates in later years to allow an adjustment in the labour market.

5 Different order for restoration model implementation over the years: the most profitable restoration models are initially adopted.

6 Different order for restoration model implementation over the years: the least costly restoration methods are initially adopted.

7 Exclusion of fencing costs (investments).

8 Adoption of real profit tax system instead of presumed profit tax system.

9 Inclusion of carbon credit revenue.

10 Timber prices over the 2015 value by one standard deviation.

11 Timber prices under the 2015 value by one standard deviation.

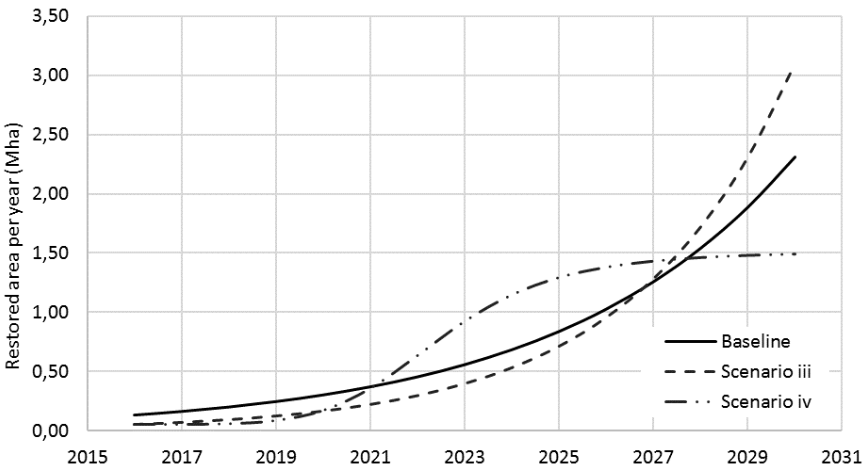
12 Combination of all positive results obtained from 1 to 11, except for 9.

13 Combination of all positive results obtained from 1 to 11.

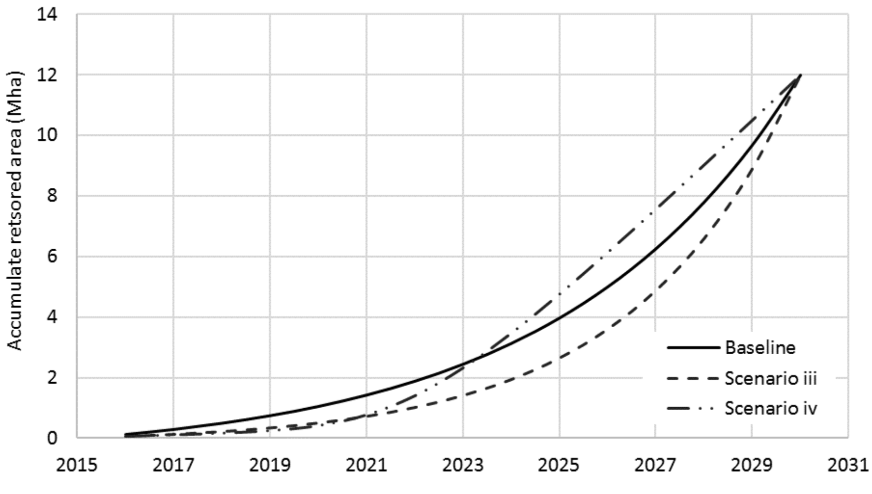
Figure 4 shows the implementation schedule differences between the baseline scenario and scenarios 3 and 4. Tables 6 to 8 show the differences between baseline and scenarios 5 and 5. In the baseline, all models are implemented in both biomes simultaneously. After 15 years, the area restored using each of the different models is the same for the baseline and the alternative scenarios (as seen in the subtotal column in each of Tables 6 to 8).

The exclusion of fencing costs in scenario 7 means that fencing costs will be considered part of the cattle project instead of the reforestation project, since it is well known that fencing is important to protect seedlings from cattle. In scenario 9, the carbon sequestration from reforestation is included in the economic analysis, internalising this positive externality. Thus, we consider that part of the carbon uptake could be transacted in forest carbon markets. We exclude deadwood, litter and soil organic carbon pools for carbon offset, following the conservative approach from the majority of afforestation/reforestation projects listed at the UNFCCC/CDM – United Nations Framework Convention on Climate Change/Clean Development Mechanism project search website (http://cdm.unfccc.int/Projects/projsearch.html).[15]

Figure 4 Different implementation schedule for baseline and scenarios 3 and 4, (a) restored area per year (b) accumulated restored area



(a)



(b)

Source: Based on PLANAVEG

Table 6 Implementation schedule per model in baseline scenario (Mha)

Biome-model/year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Subtotal*
ATF-1	0.013	0.016	0.020	0.024	0.030	0.036	0.044	0.054	0.066	0.081	0.099	0.122	0.149	0.182	0.223	1.160
ATF-2	0.005	0.006	0.007	0.009	0.011	0.014	0.017	0.020	0.025	0.030	0.037	0.046	0.056	0.068	0.084	0.435
ATF-3	0.005	0.006	0.007	0.009	0.011	0.014	0.017	0.020	0.025	0.030	0.037	0.046	0.056	0.068	0.084	0.435
ATF-4	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.019	0.023	0.028	0.034	0.042	0.218
ATF-5	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.019	0.023	0.028	0.034	0.042	0.218
ATF-6	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.019	0.023	0.028	0.034	0.042	0.218
ATF-7	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.010	0.012	0.015	0.019	0.023	0.028	0.034	0.042	0.218
AMZ-1	0.041	0.051	0.062	0.076	0.093	0.113	0.139	0.170	0.208	0.255	0.312	0.382	0.467	0.572	0.700	3.640
AMZ-2	0.015	0.019	0.023	0.028	0.035	0.043	0.052	0.064	0.078	0.096	0.117	0.143	0.175	0.214	0.262	1.365
AMZ-3	0.015	0.019	0.023	0.028	0.035	0.043	0.052	0.064	0.078	0.096	0.117	0.143	0.175	0.214	0.262	1.365
AMZ-4	0.008	0.009	0.012	0.014	0.017	0.021	0.026	0.032	0.039	0.048	0.058	0.072	0.088	0.107	0.131	0.683
AMZ-5	0.008	0.009	0.012	0.014	0.017	0.021	0.026	0.032	0.039	0.048	0.058	0.072	0.088	0.107	0.131	0.683
AMZ-6	0.008	0.009	0.012	0.014	0.017	0.021	0.026	0.032	0.039	0.048	0.058	0.072	0.088	0.107	0.131	0.683
AMZ-7	0.008	0.009	0.012	0.014	0.017	0.021	0.026	0.032	0.039	0.048	0.058	0.072	0.088	0.107	0.131	0.683
Subtotal	0.136	0.167	0.204	0.250	0.306	0.374	0.458	0.561	0.686	0.840	1.028	1.258	1.540	1.885	2.308	12.000

Table 7 Implementation schedule per model in scenario 5 – most profitable models first (Mha)

Biome-model/year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Subtotal*
ATF-1	-	-	-	-	-	-	-	-	-	0.163	0.997	-	-	-	-	1.160
ATF-2	-	0.085	0.204	0.146	-	-	-	-	-	-	-	-	-	-	-	0.435
ATF-3	-	-	-	0.104	0.306	0.025	-	-	-	-	-	-	-	-	-	0.435
ATF-4	-	-	-	-	-	-	-	-	-	-	-	-	-	0.175	0.043	0.218
ATF-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.218	0.218
ATF-6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.218	-	0.218
ATF-7	0.136	0.081	-	-	-	-	-	-	-	-	-	-	-	-	-	0.218
AMZ-1	-	-	-	-	-	-	-	-	-	-	0.031	1.258	1.540	0.810	-	3.640
AMZ-2	-	-	-	-	-	-	-	0.002	0.686	0.677	-	-	-	-	-	1.365
AMZ-3	-	-	-	-	-	0.349	0.458	0.558	-	-	-	-	-	-	-	1.365
AMZ-4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.683	0.683
AMZ-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.682	0.682
AMZ-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.683	0.683
AMZ-7	-	-	-	-	-	-	-	-	-	-	-	-	-	0.683	-	0.683
Subtotal	0.136	0.167	0.204	0.250	0.306	0.374	0.458	0.561	0.686	0.840	1.028	1.258	1.540	1.885	2.308	12.000

Table 8 Implementation schedule per model in scenario 4 – less costly models first (Mha)

Biome-model/year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*Subtotal*
ATF-1	0.136	0.167	0.204	0.250	0.306	0.098	-	-	-	-	-	-	-	-	-	1.160
ATF-2	-	-	-	-	-	-	-	-	-	-	0.209	0.226	-	-	-	0.435
ATF-3	-	-	-	-	-	-	-	-	-	-	-	-	0.435	-	-	0.435
ATF-4	-	-	-	-	-	-	-	-	-	-	-	-	-	0.218	-	0.218
ATF-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.218	0.218
ATF-6	-	-	-	-	-	-	-	-	-	-	-	-	-	0.175	0.043	0.218
ATF-7	-	-	-	-	-	-	-	-	-	-	-	-	-	0.218	-	0.218
AMZ-1	-	-	-	-	-	0.276	0.458	0.561	0.686	0.840	0.819	-	-	-	-	3.640
AMZ-2	-	-	-	-	-	-	-	-	-	-	-	1.032	0.333	-	-	1.365
AMZ-3	-	-	-	-	-	-	-	-	-	-	-	-	0.772	0.593	-	1.365
AMZ-4	-	-	-	-	-	-	-	-	-	-	-	-	-	0.683	-	0.683
AMZ-5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.682	0.682
AMZ-6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.683	0.683
AMZ-7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.683	0.683
Subtotal	0.136	0.167	0.204	0.250	0.306	0.374	0.458	0.561	0.686	0.840	1.028	1.258	1.540	1.885	2.308	12.000

Therefore, carbon offset is obtained by a 24.3% reduction in total carbon capture from Amazon and a 48.5% reduction from Atlantic Forest (percentages obtained from SNIF). We also assume that the forest carbon market will evolve so that the average prices will be maintained over time at a constant offset price of US$5.20/t$CO_2$e [average offset price from 2013s forest carbon market, according to Goldstein et al. (2014)]. Unfortunately, forecasting the forest carbon market price is still very difficult due to its relatively recent establishment. We believe that a constant price is a conservative assumption because according to Goldstein et al. (2014), the global markets for offsets from agriculture, forestry and other land-use projects transacted 32.7 MtCO_2e in 2013, a 17% increase from 2012. Simultaneously, the average offset prices fell to UD$5.20/t$CO_2$e from US $7.80/t$CO_2$e, indicating classic supply-and-demand dynamics in a market that currently has a stable but limited buyer base.

Scenarios 10 and 11 relax the assumption of the same timber prices in the whole analysed period. Thus, we calculate the sample standard deviation from CEPEA prices (eucalyptus and exotic species) from August-2002 to December-2017 (for timber prices in São Paulo state, which are representative of the Atlantic Forest) and December-2009 to December 2017 (for timber prices of Pará state, which represent Amazon prices). On average, one standard deviation variation is 15% of 2015 real prices. So scenario 10 contemplates a 15% increase of 2015 prices, while scenario 11, more pessimistic, assumes a 15% decrease of 2015 prices.

4 Results

4.1 Baseline scenario

We present the baseline scenario results in Table 9. Considering a time horizon of 35 years, medium and large agricultural producers will incur losses of approximately US$11.4 billion to implement the restoration of 12 Mha by 2030, reflected in an IRR of –0.52% per year. However, for a longer time horizon (50 years), the IRR becomes positive (4.96% per year) despite the losses observed in the NPV (US$7.7 billion, since the IRR is still lower than the cost of capital of 7.87% per year). The results also show an expected expenditure of US$22.2 billion and expected revenue of US$14.4 billion on a 50-year basis (PV). Income exceeds expenditures only in year 2035, as Figure 5 shows, which is 20 years after the beginning of implementation and five years after the deadline date for the reforestation of 12 Mha. These estimates are very conservative and do not count the positive externalities associated with the restoration.

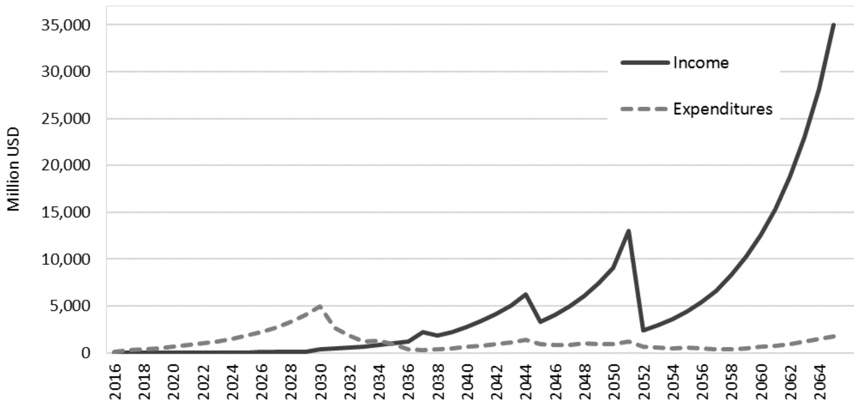
In terms of government receivables, the massive restoration program can generate US$3.7 billion in income tax and US$527.0 million in *federal revenues from other fiscal levies*, considering the longer time horizon of the analysis. Additionally, in 2030 – a year with a higher implementation area – the forest restoration activity will generate more than 218,000 direct jobs,[16] taking into account only field hands, tractor drivers, supervisors, technicians and forestry engineers. According to the estimates, after 50 years, the reforestation of 12 Mha will result in the uptake of 3.4 GtCO_2e, which represents an average carbon uptake of 68 MtCO2e per year, or approximately 3.2% of 2005 estimated emission levels (2.1 GtCO_2e, GWP-100, IPCC AR5). As mentioned, according to the iNDC, Brazil intends to reduce GHG emissions by 37% below 2005 levels in 2025 and 43% below 2005 levels in 2030, and the restoration carbon capture will contribute to reaching these targets.

Table 9 Evaluation results, 35 and 50 years, in 2015 values

Baseline scenario results	
NPV – 35 years (million US$) (r = 7.87%)	(11,429)
IRR – 35 years (% p.a.)	–0.52%
NPV – 50 years (million US$) (r = 7.87%)	(7,746)
IRR – 50 years (% p.a.)	4.96%
Expenditure VP (million US$)[1]	(22,185)
Income PV (million US$)[1]	14,439
Income tax PV (million US$)[1]	(3,699)
Direct taxes PV (PIS/COFINS) (million US$)[1]	(527)
Direct jobs[2]	218,351
Carbon capture ($MtCO_2e$)[1]	3,393

Notes: [1]considering a horizon of 50 years. [2]it refers to the maximum amount of labour demanded in the year with the highest implantation area (2030). Exchange rate: R$3.33/US$.

Figure 5 Revenue and expenditures over time in baseline scenario



4.2 Sensitivity analysis

Table 10 shows the results of baseline and alternative scenarios over a 50-year time horizon. On the one hand, a higher share of passive restoration (scenarios 1 and 2) results in greater NPV results. Despite the decrease in the income PV, the decrease in expenditures compensates for the lack of revenue from the passive restoration model. On the other hand, IRR results from baseline are better than alternative scenarios 1 and 2. Moreover, the passive restoration model is less labour intensive, as there is no harvest in this model (and consequently no forecast revenues). In addition, in these scenarios income tax decreases and carbon sequestration increases in 50 years, which represents an average carbon uptake of 82 and 97 $MtCO_2e$ per year, respectively.

Table 10 Evaluation results, 50 years, in 2015 values – baseline and alternative scenarios

		NPV (million US$) (r = 7.87%)	*IRR (%)*	*Expenditure PV (million US$)*	*Income PV (million US$)*	*Income tax PV (million US$)*	*Direct taxes PV (PIS/COFINS) (million US$)*	*Direct jobs*[1]	*Carbon uptake ($MtCO_2e$)*
1	Baseline	(7,746)	4.96%	(22,185)	14,439	(3,699)	(527)	218,351	3,393
i	50% of passive restoration	(6,513)	4.80%	(17,598)	11,085	(2,908)	(404)	178,733	4,125
ii	60% of passive restoration	(5,285)	4.54%	(13,016)	7,731	(2,121)	(282)	139,115	4,857
iii	Starting with 50,000 ha	(7,226)	4.91%	(20,447)	13,221	(3,466)	(482)	262,602	3,380
iv	Adjustment (labour market)	(7,855)	4.92%	(22,293)	14,437	(3,757)	(526)	184,102	3,398
v	More profitable met. first	(6,754)	5.22%	(20,986)	14,232	(3,841)	(519)	500,623	3,407
vi	Less costly methods first	(6,523)	4.94%	(17,819)	11,295	(3,323)	(412)	507,302	3,355
vii	Exclusion of fencing costs	(4,675)	5.85%	(19,114)	14,439	(3,756)	(527)	189,386	3,393
viii	Real profit tax system	(4,046)	6.58%	(18,485)	14,439	-	(527)	218,351	3,393
ix	Carbon credits income	(3,703)	6.23%	(22,542)	18,839	(3,896)	(687)	218,351	3,393
x	Higher timber prices (+1sd)	(6.320)	5,62%	(22.924)	16.604	(4.359)	(606)	218.351	3.393
xi	Lower timber prices (–1sd)	(9.178)	4,20%	(21.451)	12.273	(3.045)	(448)	218.351	3.393
xii	All positive adjustments except carbon credits revenue (1 + v + vii + viii + x)	2.005	8,51%	(16.911)	18.917	-	(690)	486.760	3.411
xiii	All positive adjustments (1 + v + vii + viii + ix + x)	5.746	9,89%	(17.053)	22.799	-	(832)	486.760	3.411

Notes: [1]it refers to the maximum amount of labour demanded in the year with the highest implantation area (2030). Exchange rate: R$ 3.33/US$.

The implementation schedule with a lower starting point (scenario 3) improves the NPV. However, this improvement is not followed by IRR. In scenario 4, the NPV and IRR are both worse than baseline. In relation to direct jobs, scenario 3 generates more jobs than the baseline scenario, unlike scenario 4. There are no significant changes related to income tax and carbon capture.

The implementation schedule with the early adoption of more profitable and less costly methods improves the NPV in 50 years. However, scenario 5 improves the IRR, and scenario 6 does not present any significant change in relation to the baseline scenario. In both scenarios, the number of jobs created increases significantly. However, there are no significant changes related to income tax or carbon capture.

When the investment related to fencing is excluded (scenario 7), NPV and IRR increase in 50 years. In terms of social impact, the maximum number of jobs created in 2030 is lower than the baseline scenario. No significant change occurs in income tax, and there is no impact for carbon capture.

The real profit tax system, instead of a presumed profit tax system (scenario 7), provides an increase in terms of NPV and IRR over a 50-year horizon. This system allows compensation of financial losses – the expenditure of PV decreases in scenario 8 – and is more advantageous for activities that initiate with negative or lower profits, such as the restoration program studied here. There is no impact concerning jobs or carbon sequestration.

In scenario 9, carbon credit income increases both NPV and IRR over a 50-year projection. The income PV grows from US$14.4 billion to US$18.8 billion, and more income tax and other direct taxes are generated. However, there is no impact in terms of jobs. An increase in the carbon offset price would clearly improve these results, but its price would have to increase to US$10.20/t$CO_2$e (95% increase) for a positive NPV in 50 years.

The timber prices are relaxed in scenarios 10 and 10. In a context of lower timber prices, NPV is reduced almost by the same amount as the revenue loss. On the other hand, when prices are one standard deviation higher than the 2015 values, the NPV is positively affected, and IRR increases by 0.66 pp from baseline.

Combining all positive results (scenarios 12 and 13), the NPV and IRR results become even more favourable to forest restoration activity.

In scenario 12 without fencing costs (7), a real profit tax system (8), an early implementation of the most profitable methods (5) and higher timber prices (10), there is a significant increase in both NPV and IRR in 50 years. The total expenditure PV decreases from US$22.2 billion to US$16.9 billion, mostly due to the compensation offered by the real profit tax system. Additionally, the number of jobs created in 2030 more than doubles when all positive scenarios are combined, caused by a relative concentration of labour-intensive models in the later years. The positive results were chosen using IRR after 50 years, but alternative scenarios based on NPV as criteria do not change the main results.

When adding the carbon credit revenues (scenario xiii), the results become even more favourable to forest restoration activity. In the 50-year cash flow, the NPV is about US$5.7 billion and the IRR almost reaches 10% p.a. due to the increase in the income PV.

Scenarios 12 and 13 are the only ones in which IRR is higher than the discount rate of 7.87%, demonstrating that carbon credit incentives are very attractive to the proposed project. This result is particularly important since according to the UNFCCC manual, one of the requirements for eligibility of an afforestation/reforestation project as a clean development mechanism (CDM) project activity is the need for financial incentives under the CDM (UNFCCC, 2013).

Overall, higher impacts in NPV and IRR are obtained by the exclusion of fencing costs, the adoption of a real profit tax system and the revenue generated by carbon credits.

In terms of tax revenue, a higher percentage of passive restoration methods and an implementation schedule with 50,000 ha as a starting point make the government revenue lower than our baseline scenario. However, scenario 11 shows that carbon credits benefit both investors and the government, increasing its tax revenue. Our results also show that the number of direct jobs is strongly influenced by the ordering of method implementation, resulting in a significant increase in the number of jobs generated in 2030 for scenarios 5 and 6. Carbon uptake is more influenced by projects with a higher percentage of passive restoration.

5 Final remarks

In Brazil, 16% of the Amazon Forest and 60% of the Atlantic Forest have been cleared. It is common sense that deforestation is a major contributor to climate change, which has spurred action to implement risk-mitigation initiatives. In this context, the Brazilian government recently stated in its iNDC the commitment to restore 12 Mha of degraded areas by 2030.

The Brazilian Forest Code already established important instruments for regulating and stimulating forest restoration in the country. However, this large-scale reforestation still poses several challenges, such as the opening of new markets – both for inputs and consumers – the availability of labour at the specific sites, and the land opportunity cost. More importantly, the main unanswered question is the economic feasibility of the 12 Mha restoration. This is the first study to economically evaluate, using traditional valuation methods, the massive reforestation proposal by considering ecological restoration that addresses socio-economic attributes.

According to the baseline/conservative scenario, the recovery of these areas is economically unfeasible: The NPV is negative, ranging from US$7.7 billion (50-year horizon) to US$11.4 billion (35-year horizon). The real IRR becomes positive over a longer time span (4.96% per year in 50 years against –0.52% per year in 35 years) but is nonetheless lower than the average cost of capital (7.87% per year).

The alternative scenarios considered in this study relax some of the baseline assumptions and change the results. If a higher NPV is considered as the main criterion for analysis, a method with a higher percentage of passive restoration presents better results due to the lower expenditure over the years. On the other hand, if the criterion for analysis is a greater IRR, a method with less passive restoration and more profitable implementation is recommended to increase the value of the program.

The sensitivity analysis also shows that the adoption of the real profit tax system (instead of the presumed profit tax system) and the inclusion of the revenue generated by carbon credits have a strong impact on the economic feasibility of the forest restoration analysed.

Therefore, when a different implementation schedule is considered, together with the exclusion of fencing costs, the change to a real profit tax system, more favourable timber prices and the income generated by carbon credits, the real IRR achieves 9.89% per year, much higher than the 7.87% cost of capital considered. In this scenario, almost 500 thousand direct jobs will be created in 2030 and the total carbon withheld will reach 3.4 $GtCO_2e$ after 50 years, which represents an average carbon uptake of approximately 0.07 $GtCO_2e$ per year, or approximately 3.2% of 2005 estimated emission levels (2.1 $GtCO_2e$, GWP-100, IPCC AR5). According to the iNDC, Brazil intends to reduce GHG emissions by 37% below 2005 levels in 2025 and 43% below 2005 levels in 2030, and the restoration carbon capture will contribute to reaching these targets.

To sum up, the massive reforestation proposed by the Brazilian government can be economically feasible if the specific conditions revealed in this study are considered. In terms of public policy, it is important for the government to guarantee the identification of the LR areas inside rural properties and ensure enforcement of the Brazilian Forest Code. Once the FC conditions are enforced, the labour market and the market for inputs must be developed to consistently supply the reforestation market. Since many positive externalities are not internalised in this study (such as the guarantee of biodiversity or the protection of watersheds), the socio-environmental results could be even higher. Thus, from the government's point of view, there is room to create instruments to improve the feasibility of reforestation.

Due to this study's limitations, our future research includes modelling and forecasting the markets for inputs. We also intend to study the acceptability of non-timber products in the Brazilian economy. If some of these products have potential consumer demand, it is possible to have additional revenue from the exploitation of this activity. Additionally, we intend to include in our future estimation the land cost opportunity (for LR areas), payments for environmental services, transportation prices for restored timber and carbon market prices.

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Notes

1 The measures attempt to reduce GHG emissions by 37% by 2025 and by 43% by 2030 (to 1.3 $GtCO_2e$ gigatons of CO_2 equivalent and 1.2 $GtCO_2e$, respectively) compared to the total gas emissions in 2005. Several non-binding targets were presented as additional information in order to illustrate a pathway to achieve these objectives for 2025 and 2030. Besides the restoration/reforestation of 12 Mha of forests by 2030, the other main non-binding targets are:

   a strengthening policies and measures to achieve zero illegal deforestation in the Brazilian Amazon by 2030

   b compensating for GHG emissions from the legal suppression of vegetation by 2030

   c an 18% increase in the use of biofuels in the energy mix by 2030

   d reaching 45% renewable energy sources in the energy mix by 2030

   e encouraging the implementation of low-carbon agriculture and the recovery of 15 Mha of degraded pastures by 2030

   f promoting the use of clean technologies in industry and measures to stimulate greater energy efficiency.

2 In November 2017, the final version of National Native Vegetation Recovery Plan – PLANAVEG (Ministério do Meio Ambiente, 2017) was released. Since our study was conducted considering some assumptions from the preliminary version of PLANAVEG (Ministério do Meio Ambiente, 2014), comments related to these different versions are included as endnotes through the article. It is interesting to notice that the objectives in PLANAVEGs final version were slightly changed in relation to the preliminary one, and ended up as 12 Mha of forest restoration up to 2030 mainly in PPA and LR areas, which matches the assumptions of our study.

3 Although there is an established general carbon market, it is still incipient. Less than 1% of CDM projects registered with the UN are forestry projects.

4 The Legal Amazon is defined by law and includes all states of the North region (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins) and Mato Grosso state (Midwest Region) and part of Maranhão state (Northeast region). Though called Legal Amazon, this region has three different biomes (Amazon, Cerrado and Pantanal).

5 The municipality is the local administrative unit in Brazil. It is akin to a county, except with a single mayor and municipal council. Municipalities range from lightly populated rural ones with one or two small towns to heavily populated urban ones that are part of greater metropolitan regions. There are no unincorporated areas in Brazil.

6 Brazil's system of protected areas (Conservation Units Bill, 2000) defines a conservation unit as a "territorial space and its environmental resources, including jurisdictional waters, with relevant natural characteristics, legally instituted by the Government, with conservation objectives and defined limits under a special administration regime, which is subject to appropriate guarantees of protection."

7 According to the terms of Article 50, numeral II, of Law 6,746 of 10 December 1979, a FM is an agrarian unit that represents the minimum area required to consider the rural property economically viable. The fiscal module of each municipality, expressed in ha, is determined by the National Institute for Agrarian Reform and Colonization (INCRA) taking into account the following factors:

   a the predominant form of exploitation

   b the income generated from this predominant form of exploitation

   c other forms of exploitation that are significant when it comes to income or exploited area.

8 The Rural Environmental Registry (CAR) is an electronic registry, mandatory for all rural properties, forming a strategic database for the control and monitoring of forests, as well as for environmental and economic planning of rural properties.

9 PLANAVEGs final version (Ministério do Meio Ambiente, 2017) also considers the majority of restoration in Amazon and Atlantic Forest biomes (76%). PLANAVEGs preliminary version did not present any biome regionalisation.

10 Originally, PLANAVEG proposed to recover 12.5 Mha in 20 years, starting in 2015 with 0.05 Mha and ending in 2034. PLANAVEGs final version (Ministério do Meio Ambiente, 2017) considers a recovery of 12 Mha up to 2030, starting in 2017 with 0.05 Mha and ending in 2030, with an average annual growth rate of 38.73%.

11 Data can be obtained upon request to the authors.

12 In PLANAVEGs final version (Ministério do Meio Ambiente, 2017), it would be equivalent to scenario 3.

13 In PLANAVEGs final version (Ministério do Meio Ambiente, 2017), it would be equivalent to scenario 4.

14 There is no equivalent scenario in PLANAVEGs final version (Ministério do Meio Ambiente, 2017).

15 The term afforestation is used by UNFCCC/CDM and one of its possible definitions is the planting of trees for forest formation in areas where there were no forests under the current climatic conditions; the term reforestation presupposes the existence of forests in the not too distant past.

16 The amount of labour demanded in the year with the highest implementation area (2030) is estimated based on the projection of the area to be restored. The total number of employees required over the 15 years will imply double counting.