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RESEARCH GAPS AND PRIORITIES IN SILVICULTURE OF NATIVE SPECIES IN BRAZIL

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EXECUTIVE SUMMARY

Highlights

- Development of native species silviculture is imperative to promote the forestry sector in Brazil and help the country to achieve its NDC (Nationally Determined Contribution).
- A pre-competitive Research & Development (R&D) Platform needs to be built in order to boost the sector.
- This working paper describes four investment scenarios to establish an R&D Platform based on native species from the Amazon and Atlantic Forest biomes of Brazil.
- Some of the main findings include: (1) based on the four investment scenarios, investments from USD 3.79 (BRL 14.6) to USD 7.30 (BRL 28.1) million may be required, which represents less than 0.05% of Brazilian investment in R&D, and (2) an area as small as 10,000 hectares would already justify an investment in the R&D Platform.
- One of the proposed investment scenarios showed a return of USD 2.39 in benefits per each USD 1 invested in R&D.

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Background

Brazil has committed itself to restore and reforest 12 Mha of degraded land as part of its effort to achieve the climate goals in its NDC (Nationally Determined Contribution). The Paris Agreement, Initiative 20 x 20 and The Bonn Challenge are all initiatives that recognize forest restoration and reforestation as the best and cheapest strategy to mitigate climate change and improve the resilience of economies and societies. Accelerating and increasing the scale of reforestation programs by expanding the planted area with native species trees, has become an urgent issue. Silviculture of native species could be a viable business that would contribute to the reforestation target. Currently in Brazil, however, tropical timber is being sourced mainly from natural forests, contributing to deforestation, despite some successful experiences.

It is broadly recognized that shifting tropical timber supply from natural forests to forest plantations is a huge challenge. The shift requires not only great efforts from law enforcement, but also the development of science-based solutions. Promoting silviculture that makes use of native species requires more information on aspects such as best origin and quality for seed harvesting, seed and seedling production, planting density, planting conditions (shadow or light), growth rates, arrangement of species, handling activities (thinning, pruning), insect and disease control, cutting cycle length, and timber quality of planted species, among other aspects. Although several species have already been studied, results may vary according to climatic region and methodology used. Many studies have been carried out in natural forests and they need to be adapted to forestry plantations.

The Need for More Research

This working paper assesses gaps in the current state of research knowledge and defines priorities for promoting silviculture with native Brazilian species. The paper identifies the studies carried out in Brazil on silviculture with native tree species, defines the main research gaps, and proposes research priorities to be supported by an R&D Platform. It also quantifies the investment required to promote the proposed research and to overcome the barriers identified in the gap analysis, quantifies the benefits of the R&D Platform in the short, medium, and long term, and quantifies the optimum economic scale to justify investments, based on market demand for tropical timber and gains in economic, social and environmental development.

The paper proposes a pre-competitive R&D Platform for the most promising tree species. From a list of 45 pre-selected native tree species found in the Amazon and Atlantic Forest biomes, 30 priority species were chosen, 15 for the Amazon biome and 15 for the Atlantic Forest biome. Some species of the Atlantic Forest biome also occur in the Amazon and vice versa. However, 16 out of those 30 species also occur in the Cerrado (Brazilian Savanna) biome, making it possible to apply some of the research priorities proposed to the Cerrado.

The relatively high number of priority species selected for the pre-competitive R&D program is justified, mainly because silvicultural systems for native species are more complex than those for exotic species. A large and diverse base of species, planted together, is required to meet the goals of the climate and biodiversity conventions. It is necessary to plant different species together (i.e., *in consortium*).

Four investment scenarios are proposed to build an R&D Platform. The scenarios were based on the number of species (14, 20 or 30) and the investment period (10 or 20 years). Scenario I (with a 20-year timeframe, and 30 species) requires an investment of around USD 7.30 (BRL 28.1) million and was considered to be the best scenario to support research for a new forest economy based on native species. The largest investment is the cost of reforesting 500 hectares with experimental trials, which also includes the annual monitoring cost over 20 years.

Key Findings

The major factors affecting profitability of native species plantations are distance to ports and the mix of species used. The Amazon biome is much further from ports (mean distance 2,000 km) than the Atlantic biome (mean distance 300 km), which adds greatly to costs. And mixing exotic species with native species increases profitability because exotic species incorporate the benefits of R&D over the last 40 years that has resulted in more efficient management systems and higher yields.

A scale as small as 10,000 hectares would already justify an investment in the R&D Platform, although there is enormous potential to increase the scale of silviculture of native tree species to millions of hectares to fulfill the global demand for timber. Further, yield increases of 35% to 56% seem to be the most realistic.

Silviculture with native tree species could help to meet growing demand for tropical timber and could generate other additional benefits. Additional benefits include helping to reduce deforestation and degradation, increasing local biodiversity, removing millions of tonnes of carbon dioxide (CO_2) from the atmosphere, increasing green jobs and income, and reducing the cost of restoration and reforestation.

There is no legal barrier to the establishment of native tree species plantations for economic or environmental purposes. However, unclear and complex administrative structures and processes hinder progress. Urgent efforts are necessary to clarify the relevant forestry laws and define legal competence at government level.

To address knowledge gaps and overcome implementation challenges, it is essential to form a cooperative network and develop a pre-competitive R&D Platform. The platform should involve leading public universities and research institutions with forestry knowledge, as well as forestry companies, and the government. A concerted research effort could emulate the success of the programs developed for eucalyptus and pine species in recent decades. These exotic species are now mainstays of the Brazilian forestry industry. There is an urgent need to develop new commercially applicable technologies to improve the productivity and performance of the main Brazilian native tree species.

1. INTRODUCTION: FOREST RESOURCES AND FORESTRY IN BRAZIL

Brazil is rich in forest resources, with more than 500 million hectares (Mha) of native forests and approximately 8 Mha of planted forests. Thanks to the area and diversity of its forests, Brazil is a leading supplier of products such as wood, food, oils and resins, and environmental services including carbon storage. However, the country also has a tradition of unsustainable use of land. In Brazil, a unique program was created to restore 15 million hectares of degraded lands in the Atlantic Forest biome by 2050, in order to support the implementation of the Forest Code (Law 12.651/12), and achieve 30% of forest cover (Calmon et al. 2011). In Brazil, this forest deficit is known as an “environmental liability” or an area that must be reforested to comply with the current legislation.

A significant part of the liability will be reduced through restoration and reforestation with native species. Brazil has an estimated 30–70 Mha of degraded pasture lands with low suitability for agriculture that could benefit from restoration and reforestation (Dias-Filho 2014). Most of this vast area is concentrated in the Amazon and Atlantic Forest biomes. Greater efforts are needed to promote forestry in these areas and create new forests with economic value.

The known flora in Brazil’s forests comprise approximately 8,715 tree species, representing 14.5 percent of all known tree species in the world (Beech et al. 2017). Of these, a few hundred species are mentioned as high quality for timber production (Mainieri and Chimelo 1989; Ibama 1997; Nahuz et al. 2013). However, only a few species from Brazil’s natural forests are harvested. In the state of Mato Grosso, for example, four species (*Qualea* sp. or cambará, *Goupia glabra* or cupiúba, *Erisma uncinatum* or cedrinho, *Mezilaurus itauba* or itaúba) represent 63 percent of all timber harvested in natural forests (Ribeiro et al. 2016).

In Brazil, 14 million m^3 / year of logs are extracted from natural forests (Veríssimo and Pereira 2014). Timber is one of the most important products from the forest, but if current consumption trends continue, tropical timber from natural forests could be in short supply, leading to rising prices over the next 50 years (Buongiorno 2015). This situation has created the urgent need to start massive reforestation programs to meet current and future demand for solid timber from planted forests and relieve pressure on natural forests (FAO 2013).

Several countries in Europe, North America, Central and West Asia, and North Africa have invested in the production of timber from local native species. But in some countries, like Brazil, investment in silviculture has been growing only for production of exotic species (Payn et al. 2015). Brazil has enormous natural capital and the means to transform the conservation and sustainable use of its environmental assets into opportunities, enabling the country to face a changing climate and to promote socio-economic prosperity (Metzger et al. 2019). Consumption of wood from native species is high in Brazil, and often illegal, and it is essential to promote forestry with native tree species.

To promote forestry with native species, more information is needed on the sources and quality of seeds, seedling production, plantation density, planting conditions (shade or light), growth rates, arrangement of species, handling activities (thinning, pruning), insect and disease control, cutting cycle length, and timber quality of planted species, among other subjects.

The development of silviculture using tropical native tree species should follow the example established by the development of eucalyptus and pine production in past decades. These species, both dominant in Brazil’s national forestry sector, were promoted by the development of production techniques and genetic improvement. A parallel and robust R&D Platform for native species must be based on the information available, either in the form of articles, thesis, and books or in the hands-on experience of managers, researchers, and field practitioners. State-of-the-art information on each relevant species will provide the roadmap for development. An R&D program in silviculture of native species trees is an innovative approach and could provide economic, social, and environmental benefits. This is one of the reasons why the Brazilian Coalition on Climate, Forestry and Agriculture, an alliance of over 200 private sector and civil society organizations, prioritized the establishment of an R&D Platform, as part of its vision to support Brazil's transition to a low-carbon economy.

1.1. Objectives

Knowledge on silviculture with native species has not been organized or consolidated, hindering access to technical information and risk assessments that could aid decision makers and boost investor interest.

The broad objective of this working paper is to evaluate the research gaps and priorities concerning silviculture using Brazilian native tree species and to design a pre-competitive research and development (R&D) Platform to promote the use of the most promising species. The specific objectives are:

- Identify the main research undertaken in Brazil on silviculture using native tree species;
- Define the main research gaps and propose research priorities to be supported by an R&D Platform for the silviculture of native tree species in Brazil;
- Quantify the investment required to promote the proposed research and overcome barriers identified in the gap analysis;
- Quantify the short-, medium-, and long-term results of research (1 to 5 years; 5 to 10 years; and 10 to 20 years, respectively) in economic terms;
- Quantify optimum economic scale to justify R&D Platform investments, based on market demand for tropical timber and benefits for economic, social and environmental development.

The Amazon and Atlantic Forest biomes are the focus of this working paper, because of existing research initiatives, the diversity of their forest species, and the edaphoclimatic potential of these biomes for native timber production.

1.2. The Need for an R&D Platform

The challenge of accelerating and scaling up forest restoration and reforestation is enormous. The Bonn Challenge initiative has set a target to restore 150 Mha of degraded lands and forests by 2020 and 350 Mha by 2030; and Brazil's NDC (Nationally Determined Contribution) under the Paris Agreement on climate change has committed the country to restoring or to reforesting 12 Mha by 2030. These targets are only viable if business models mixing native timber and non-timber tree species are part of the solutions package.

An essential element in meeting these challenges will be the establishment of a cooperative network, known as the Brazilian Coalition on Climate, Forestry and Agriculture, involving leading public universities and research companies with forest expertise, as well as forest companies, and the government. Such a network will draw on the experience of institutional arrangements already established for exotic species.

The scaling up of business models for native species depends on the development of a pre-competitive R&D program to improve the productivity and performance of the leading Brazilian native tree species. A pre-competitive R&D program may be defined as cooperative research conducted jointly by normally competing institutions for the purpose of developing new commercially applicable technologies (Longo and Oliveira 2000).

The Brazilian Coalition on Climate, Forests and Agriculture—which supports a low-carbon economy in Brazil—defined as one of its top priorities the implementation of a pre-competitive R&D program for native tree species. Such a program would be similar to that established for eucalyptus and pine plantations over the past 50 years, based on enhanced production techniques and genetic improvement (Brazilian Coalition on Climate, Forests and Agriculture n.d.). However, knowledge on silviculture for native species is currently scattered and disorganized, which limits access to technical information and risk assessments needed by both decision-makers and potential investors.

Decreasing deforestation and increasing forest restoration and reforestation are currently the most efficient and cost-effective ways to mitigate global warming (Bastin et al. 2019). Improving silviculture with native species through a well-designed R&D program brings great benefits to the climate, to biodiversity conservation, and according to our analysis may also be a good business.

An important part of the effort must be to gather and systematize all available information on native species, whether from the literature or the personal experience of managers, researchers, experts, and field practitioners. The resulting knowledge of the relevant species will form the basis for designing and implementing a robust pre-competitive R&D Platform for native tropical tree species.

2. APPROACH AND METHODOLOGY

In the following items, the methodology adopted by researchers and experts was designed to: organize a literature review on forestry with native tree species in the Amazon and Atlantic Forest biomes; define a pre-list of 45 species with wood potential; establish research topics considered most important for the forestry of 30 priority native species in a short-, medium- and long-term R&D Platform; estimate platform costs and profits; and estimate the return and scalability of an R&D program.

2.1 Establishing a Baseline of Knowledge on Silviculture with Native Species

A three-day workshop was organized with the participation of researchers and specialists in native forest species from various Brazilian institutions and regions (Appendix A). Prior to the workshop, a group of experts conducted a literature review on native tree silviculture and prepared a pre-list of 45 species with timber potential. Species were chosen in the pre-selection process based on the following conditions:

- Native species of the Atlantic Forest, the Amazon or both;
- Demonstrated use as a timber species;
- Viable in homogeneous and mixed plantations, intercropping, and agroforestry systems.

The ability of the native tree species to provide non-timber products as added value was also considered. But it was not a required condition for including a species in this pre-list.

The criteria used to select species for the initial (pre-selection) list are shown in Table 1.

Table 1 | **Criteria Used in Selecting Tree Species in the Base List**

PRIORITY LEVEL	CRITERIA
1A	Fast growth rate (> 0.8 cm of annual diameter increment), desired form for the timber market (sawn wood), and perceived market value
1B	Slow growth (< 0.8 cm of annual diameter increment), desired form for the timber market, and perceived market value
2	Difficult management (e.g., poor trunk form or susceptible to pests and disease), but perceived market value
3	Good silvicultural characteristics but limited knowledge in the timber market

The workshop was held on September 3–5, 2018, at the National Forest of Ipanema (Flona Ipanema), in Iperó, São Paulo State. It involved presentation and discussion of the findings from the literature review and survey. Workshop outputs included: a list of selected species; the definition of research gaps and priorities, for each species; and an outline of the R&D Platform, including the scale, investment needs, expected results, and cost-benefits. The process of collecting quantitative data was broad and participative. At the end of discussions, a debate was organized by the Workshop's Planning Team.

Prior to the workshop, researchers and experts (Appendix A) in each thematic area were consulted on the state of the art in research in their field of knowledge, and, during the workshop, participants were divided into four working groups, each considering related issues in a thematic area (Table 2), with the goal of promoting exchange of experience and debate. One specific group focused on the analysis of public policies and legislation that could present obstacles to the establishment of a native species forestry business.

Table 2 | **Thematic Areas Considered by Workshop Participants**

GROUP	THEME AREA
1	Seeds
	Seedlings
	Vegetative propagation
	Genetic improvement
2	Ecophysiology
	Mycorrhizal and Rhizobium
	Plantation management
3	Wood technology
	Forestry zoning
	Production modeling
	Benefits and carbon
4	Economy and market
	Forestry policies and legislation

Other debate groups were tasked with:

- Defining the priority species for silviculture (from 45 pre-selected species) based on knowledge and existing gaps. During the workshop groups were free to include new species;
- Establishing research priorities in the short (0-5 years), medium (5-10 years) and long term (>10 years);
- Estimating, as a group, aspects such as the profit, infrastructure, and necessary preliminary cost of undertaking an R&D Platform on silviculture with native tree species in the short, medium and long term.

In developing answers, the participants took into account existing literature and ongoing research projects, and research gaps and priorities.

The theme coordinators of each working group were encouraged to suggest and invite other researchers and collaborators to provide additional input. They all answered questions (see below) and filled out spreadsheets (Table 3), based on what they considered to be their own relevant personal work experience (including unpublished information), study-related experience (research and/or technical work), and empirical and practical knowledge (experiential knowledge). Their efforts were supported by interns from graduate and post-graduate programs of the researchers' institutions, who contributed, under the researchers' guidance, by searching for literature or information on the species and their themes. These themes were: seed and seedlings, vegetative propagation, genetic improvement, wood technology, plantation management and modeling, topo-climatic zoning, market for wood products and forestry policy and legislation. Each coordinator had the autonomy to choose or remove variables in each theme, therefore building a database according to the available expertise.

The questions answered by researchers were:

- Which species have research gaps in your thematic area?
- What is the state of the art of research in your thematic area?

2.2 Selecting Species and Identifying Research Priorities

A methodology proposed by Dr. Antônio Paulo Mendes Galvão, former Director of Embrapa (Brazil's public research organization on agriculture, livestock and forest), was used to standardize the prioritization of tree species (from the 45 pre-listed species), themes, and research in the different working groups (Table 3). This process was necessary because prioritization in the environmental and forestry sectors is even more essential than in agriculture, since trees respond more slowly to management than agricultural crops. Each working group assigned a weight (relative importance) to the established criteria and then, based on the previously developed database and personal experiences, they assigned grades from zero (worst scenarios) to three (best scenarios) to the proposed criteria. Then, the score (relative grade in terms of importance) for each criterion was calculated and the sum of scores for each species was determined (Table 7). At the end, the species with the highest scores were selected.

The goal of the prioritization was to highlight those native species most suitable for the development of a large-scale and economically viable silvicultural program, similar to that employed for eucalyptus and pine. The initial focus was on species with already developed markets and further selection of a few species to enable efficient use of financial and human resources. However, workshop groups were free to include new criteria and metrics after discussing with their colleagues, but always following the prioritization method, which enabled comparison among groups.

Other important considerations included the estimated costs and benefits of an R&D program in the short, medium, and long term; the potential of the species to adapt to, and to mitigate the impacts of, climate change; the resilience of ecosystems; and production processes.

Table 3 | **Template to Prioritize Native Tree Species for Use in Plantations**

CRITERIA		RI (%)	GRADE	SCORE
Economic Characteristics	Consolidated market			
	Promising market			
	Price of the timber or non-timber products			
Efficiency of the Research Process	Deadline to obtain results			
	Research cost			
Sivicultural Characteristics	Growth			
	Adaptation to different soils			
	Adaptation to different climates			
	Occurrence of plagues and diseases			
Total score of the subject/project/action (sum of scores)				

Note: RI (%) = Relative Importance Considering the Criteria Economic Characteristics, Efficiency of the Research Process, and Silvicultural Charactheristics; Grade: Best Evaluation = 3; Intermediate Evaluation = 2; Worst Evaluation = 1; Insignificant or None = 0; Score = (RI.Grade)/100

2.3 Developing Investment Scenarios

After the workshop, the authors established four investment scenarios involving varying timeframes, numbers of tree species and planted areas:

- **Scenario I** - timeframe of 20 years with 30 species, in an area of 500 ha
- **Scenario II** - timeframe of 10 years with 30 species, in an area of 500 ha
- **Scenario III** - timeframe of 10 years with 20 species, in an area of 333 ha
- **Scenario IV** - timeframe of 10 years with 14 species, in an area of 500 ha

The scenarios were divided into 5 experimental locations in the Amazon and 5 in the Atlantic Forest biomes, aiming to cover a range of climatic and floristic gradients of these biomes.

This allowed for an estimation of the benefits and scale (area of planting) of a pre-competitive R&D Platform for silviculture with native tree species for the Amazon and Atlantic Forest biomes.

To estimate and monetize the additional benefits of an R&D Platform, two models based on the experience of the VERENA project (focused on demonstrating the technical and economic feasibility of large-scale restoration and reforestation with native species in Brazil) were used (Batista et al. 2017), and compared the baseline results (tree planting with no additional R&D) with the predicted results of tree planting with benefits of input from an R&D Platform. Specific benefits assessed as a function of scale and R&D investments were carbon and return on investment. The following three sections present the outputs of the workshop and detail findings in the three areas outlined above: the current research base, the identification of suitable native tree species and research needs, and the development of investment scenarios for establishing an R&D Platform.

3. THE BASELINE OF KNOWLEDGE ON SILVICULTURE WITH NATIVE TREE SPECIES

The total number of citations in the literature, per theme, for all 45 pre-selected species (Table 4) is higher than the number of articles because the same article may cite more than one variable and sometimes more than one species. Genetic improvement, plantation management, and seeds represent approximately 78 percent of the total number of citations of variables in published research.

Of the 45 pre-selected species, 10 account for 64 percent of all citations of variables whereas 21 species represent just 8.8 percent of all citations—some of them are not cited at all. These results are evidence that, although a substantial number of studies have been published on subjects relevant to silviculture with native species, they focus on very few species.

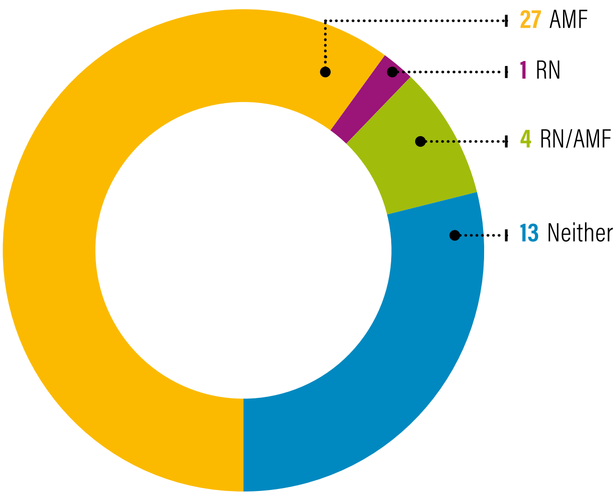
The species that are the subject of the greatest volume of research are in the Atlantic Forest biome, but even for these species there are gaps in some of the themes. An important part of ongoing or previous research on some topics, such as seedlings and seeds, is related to the species ecology and not directly to silviculture of native species. It is noteworthy that the literature review, and the conversations and interviews held with the theme coordinators, show that most of the technical recommendations for silviculture are based on researchers' first-hand experience and observation of the species' behavior in restoration interventions, and not necessarily in silvicultural plantings.

Table 4 | **Number of Citations in the Literature of Selected Themes for the 45 Pre-Selected Native Tree Species**

SPECIES	THEMES									
	SEEDS	SEED-LINGS	VEGETATIVE PROPA-GATION	GENETIC IMPROVEMENT	WOOD TECHNOLOGY	PLANTATION MANAGE-MENT	TOPO-CLIMATIC ZONING	FOREST MODELING	TOTAL CITATIONS FOR EACH SPECIES	NUMBER OF CITATIONS RELATIVE TO TOTAL NUMBER OF CITATIONS
Peltophorum dubium	47	13	24	304	11	57	0	0	456	13.81
Myracrodruon urundeuva	28	9	6	268	0	37	0	6	354	10.72
Balfourodendron riedelianum	36	2	0	214	1	33	0	3	289	8.75
Araucaria angustifolia	29	5	54	130	7	30	0	2	257	7.78
Cariniana legalis	7	6	0	206	7	19	0	1	246	7.45
Hymenaea courbaril	41	18	5	4	8	53	0	15	144	4.36
Cordia trichotoma	28	10	25	7	5	29	0	2	106	3.21
Schizolobium parahyba var. *amazonicum*	0	0	7	48	9	27	1	11	103	3.12
Calophyllum brasiliense	37	13	23	0	0	20	0	0	93	2.82
Virola surinamensis	20	3	0	64	0	3	0	2	92	2.79
Cedrela fissilis	0	0	26	0	1	61	0	0	88	2.67
Swietenia macrophylla	0	0	40	0	6	26	0	9	81	2.45
Dalbergia nigra	48	7	16	0	5	5	0	0	81	2.45
Carapa guianensis	40	6	6	0	1	10	0	13	76	2.30
Schizolobium parahyba	0	0	6	22	6	40	0	1	75	2.27
Cordia goeldiana	21	4	0	0	0	29	0	9	63	1.91
Terminalia argentea	22	0	0	27	0	8	0	4	61	1.85
Berthollethia excelsa	22	5	6	0	0	8	0	15	56	1.70
Handroanthus serratifolius	15	2	12	0	5	9	0	10	53	1.60
Astronium graveolens	11	2	0	0	6	30	0	1	50	1.51
Jacaranda copaia	22	5	0	0	0	12	0	9	48	1.45
Plathymenia reticulata	31	3	6	0	0	7	0	1	48	1.45
Copaifera langsdorffii	0	0	13	0	5	28	0	2	48	1.45
Zeyheria tuberculosa	12	4	0	3	5	17	0	3	44	1.33
Dipteryx odorata	8	4	0	0	1	14	0	5	32	0.97
Paubrasilia echinata	18	0	0	3	7	2	0	0	30	0.91
Tachigali vulgaris	0	0	0	0	9	4	1	12	26	0.79
Dipteryx alata	0	14	12	0	0	0	0	0	26	0.79
Schefflera morototoni	10	0	0	0	0	6	0	8	24	0.73
Anadenanthera peregrina var. *falcata*	0	0	0	12	0	11	0	0	23	0.70
Lecythis pisonis	13	0	0	0	5	0	0	4	22	0.67
Ceiba pentandra	15	4	0	0	0	0	0	0	19	0.58
Manilkara longifolia	6	0	0	0	5	0	0	7	18	0.54
Simarouba amara	3	3	0	0	0	4	0	4	14	0.42
Bagassa guianensis	0	0	0	0	2	9	0	3	14	0.42
Joannesia princeps	0	0	0	0	5	7	0	0	12	0.36
Vochysia maxima	3	2	0	0	0	0	0	5	10	0.30
Pterigota brasiliensis	0	0	0	0	5	2	0	3	10	0.30
Terminalia mameluco	0	0	0	0	5	0	0	0	5	0.15
Parkia gigantocarpa	0	0	0	0	3	0	0	0	3	0.09
Vataireopsis speciosa	2	0	0	0	0	0	0	0	2	0.06
Myrocarpus frondosus	0	0	0	0	0	1	0	0	1	0.03
Enterolobium maximum	0	0	0	0	0	0	0	0	0	0.00
Couma utilis	0	0	0	0	0	0	0	0	0	0.00
Aspidosperma album	0	0	0	0	0	0	0	0	0	0.00
N	**595**	**144**	**287**	**1312**	**135**	**658**	**2**	**170**	**3,303**	**100**
N%	**18.0**	**4.4**	**8.7**	**39.7**	**4.1**	**19.8**	**0.1**	**5.2**	**100**	

The number of citations found for root-associated microbial symbionts to the 45 pre-selected native species for silviculture was low. The survey distinguished only the presence of nodulation by N fixing bacteria (rhizobia), presence of arbuscular mycorrhizal fungi (P availability), and association of arbuscular mycorrhizal fungi and rhizobia (Figure 1 and Appendix D).

Figure 1 | **Root-Associated Microbial Symbionts Acting on the 45 Pre-Selected Native Tree Species**



Notes:
AMF = presence of arbuscular mycorrhizal fungi;
RN = rhizobia nodulation;
RN / AMF = association of rhizobia and arbuscular mycorrhizal fungi;
Neither = without rhizobia nodulation and without mycorrhization.

Although several species have already been studied within some of these research thematic areas, the results may vary according to climatic region and methodologies used. Many studies are out of date and were carried out in natural forests, so they need to be adapted to forestry plantations. It is also important to mention that some of these studies may still present basic questions on the ecology of species and not comprehensive knowledge for silviculture of native species. Ideally, new studies would be conducted on all of the selected species by an integrated research network, using standardized methods for all climatic regions.

4. SELECTED TREE SPECIES AND IDENTIFIED RESEARCH PRIORITIES

4.1 Priority Tree Species

Using the criteria outlined in Tables 1 and 3, workshop participants established a priority list of native species suitable for silviculture. The species classified as class 3 (Appendix B) were removed from the priority list regardless of their score in Table 3.

A total of 30 priority species were chosen, 15 for the Amazon biome and 15 for the Atlantic Forest biome (Table 5). As mentioned, during the workshop groups were free to include new species. Then, after discussions, three species, not included on the 45 species pre-list, were added to the final list. They were: *Genipa americana*, *Dinizia excelsa*, and *Copaifera multijuga*, all of them for providing good quality wood, growing well, and being the subject of ongoing research.

Some species found in the Atlantic Forest biome also occur in the Amazon and vice-versa. Sixteen of the 30 tree species also occur in the Cerrado biome (Brazilian Savanna), making it possible to extrapolate and apply some of the findings of the study to the Cerrado.

Table 5 | **30 Priority Native Tree Species Selected as Suitable for Silviculture in Atlantic Forest Biome and in Amazon Biome, Brazil.**

CLASS	SCIENTIFIC NAME*	COMMON NAME	FAMILY	OCCURRENCE AREA		
				AMAZON FOREST	ATLANTIC FOREST	CERRADO
ATLANTIC FOREST PRIORITY SPECIES						
1A	*Araucaria angustifolia* (Bertol.) Kuntze	araucaria	Araucariaceae		X	
1A	*Astronium graveolens* Jacq.	guaritá	Anacardiaceae	X	X	X
1A	*Balfourodendron riedelianum* (Engl.) Engl.	pau-marfim	Rutaceae		X	X
1A	*Calophyllum brasiliense* Cambess.	guanandi (beautyleaf)	Calophyllaceae	X	X	X
1A	*Cariniana legalis* (Mart.) Kuntze	jequitibá-rosa	Lecythidaceae		X	
1A	*Cordia trichotoma* (Vell.) Arráb. ex Steud.	louro-pardo (bay-tree)	Boraginaceae	X	X	X
1A	*Dalbergia nigra* (Vell.) Allemao ex Benth.	jacarandá-da-bahia	Fabaceae		X	
1A	*Hymenaea courbaril* L.	jatobá	Fabaceae	X	X	X
1A	*Peltophorum dubium* (Spreng.) Taub.	canafístula	Fabaceae		X	X
1A	*Plathymenia reticulata* Benth.	vinhático	Fabaceae		X	X
1B	*Handroanthus impetiginosus* (Mart. ex DC.) Mattos	ipê-roxo	Bignoniaceae	X	X	X
1B	*Myracrodruon urundeuva* Allemao	aroeira-do-sertão	Anacardiaceae		X	X
1B	*Paubrasilia echinata* (Lam.) E. Gag-non, H.C. Lima and G.P. Lewis	pau-brasil (redwood)	Fabaceae		X	
1B	*Zeyheria tuberculosa* (Vell.) Bureau ex Verl.	ipê-felpudo	Bignoniaceae		X	X
*	*Genipa americana* L.	jenipapo (jenipap)	Rubiaceae	X	X	X
AMAZON PRIORITY SPECIES						
1A	*Bagassa guianensis* Aubl.	tatajuba	Moraceae	X		X
1A	*Bertholletia excelsa* Bonpl.	castanha-da-Amazônia (Amazon chestnut)	Lecythidaceae	X		
1A	*Carapa guianensis* Aubl.	andiroba	Meliaceae	X		
1A	*Cordia goeldiana* Huber	freijó-cinza	Boraginaceae	X		
1A	*Jacaranda copaia* (Aubl.) D.Don	parapará	Bignoniaceae	X		
1A	*Schefflera morototoni* (Aubl.) Maguire et al.	morototó	Araliaceae	X	X	X
1A	*Schizolobium parahyba* var. *amazoni-cum* (Huber ex Ducke) Barneby	paricá	Fabaceae	X		
1A	*Simarouba amara* Aubl.	marupá	Simaroubaceae	X	X	X
1A	*Virola surinamensis* (Rol. ex Rottb.) Warb.	ucuúba	Myristicaceae	X		
1A	*Vochysia maxima* Ducke	quaruba-verdadeira	Vochysiaceae	X		
1B	*Dipteryx odorata* (Aubl.) Willd.	cumarú	Fabaceae	X		
1B	*Handroanthus serratifolius* (Vahl) S.Grose	ipê-amarelo	Bignoniaceae	X	X	X
2	*Swietenia macrophylla* King	mogno (mahogany)	Meliaceae	X		
*	*Copaifera multijuga* Hayne	copaíba	Fabaceae	X		
*	*Dinizia excelsa* Ducke	angelim-vermelho	Fabaceae	X		

*Organized in alphabetical order within the class indicated in Appendix B; *Species included during the Workshop, after discussion based on knowledge from experts and existing research gaps.

Thirty species is a high number with which to begin a pre-competitive R&D program, but it was justified by the workshop experts on the following grounds:

- Silviculture with native species is designed to contribute to the goals of climate change and biodiversity conventions. These goals require many species to be planted together (i.e., *in consortium*). Native species planting differs from exotic species in this respect.
- Another reason to use a diverse range of native tree species is to restore the Legal Reserve area of rural properties as part of the Forest Code requirement.
- Planting several species together (*in consortium*) requires careful selection. Some species perform better with specific species and not with others, for example, nitrogen-fixing species enhance the growth of non-nitrogen-fixing species, some may be heliophytes. To offer the necessary choice of species combinations appropriate to different ecosystems and edaphoclimatic conditions, the list of species cannot be too restricted.
- The timber market is diverse and, if native species are to compete with wood from natural forests and help decrease deforestation in the Amazon, they must offer a diversity of timber with different colors and textures and, planted for different purposes and products.
- Some species, like the *Araucaria angustifolia* (araucaria), *Virola surinamensis* (ucuúba) and *Paubrasilia echinata* (pau-brasil), have limited occurrences and must not be planted indiscriminately all over the biome. Therefore, given the high species richness in Brazil and the floristic differences among regions within the biomes, not all selected species will be used within each region and each species must be carefully analyzed in its natural area of occurrence.

The cost-benefit analysis for the R&D Platform based on the results of this study was carried out for 7, 10 and 15 species per biome, indicated according to the order of priority in each biome, and considered the possibility that financial resources would not be sufficient to meet all of the biome research priorities and species. Seven species is the minimum number stipulated by the core group of researchers that could boost the silviculture of native species at scale.

Some other important observations about the list of species should be highlighted:

- Different species occur in all three biomes – the Amazon, Cerrado, and Atlantic Forest – and, in some cases, they may occur in the transition zones between biomes. It is therefore important not to generalize recommendations of species for the entire biome, or for any region or state within the biome.
- Species vary widely in their rates of growth, due to their intrinsic ecological characteristics and their interaction with soil and climate conditions. The fastest growing species can be defined as "flagships", whereas the slowest-growing species should be integrated into silvicultural management in smaller density, to be harvested in the long term.
- Species that may present phytosanitary problems, such as *Swietenia macrophylla* (mahogany), should not be planted in high density and on a large scale, but these species may be included in low density in mixed plantations.

According to the Brazilian Secretariat of Foreign Trade, most of the listed species are of export interest. Some examples are *Carapa guianensis* (andiroba), *Balfourodendron riedelianum* (pau-marfim), *Cordia trichotoma* (bay-tree), *Swietenia macrophylla* (mahogany) and *Paubrasilia echinata* (pau-brasil). Most species with medium to high growth rates that have good to excellent wood quality are included, such as *Plathymenia reticulata* (vinhático), *Cariniana legalis* (jequitibá-rosa), *Swietenia macrophylla* (mahogany), *Virola surinamensis* (ucuúba), *Bagassa guianensis* (tatajuba), and *Jacaranda copaia* (parapará). Ongoing research experiments or good practical experiences exist for most of these species, which means they have relatively well-known forestry practices.

4.2 Research Needs and Priorities

Eight priority research themes were identified for silviculture of native tree species in Brazil: seeds and seedlings, vegetative propagation, genetic improvement, wood technology, plantation management and modeling (including nutrition, phytossanity, ecophysiology, plantation designs, thinning, arbuscular mycorrhizal interactions), topo-climatic zoning, market for timber products, and forestry policy and legislation. The main knowledge gaps in each theme are in Table 6.

Table 6 | **Priority Theme for an R&D Platform and the Main Research Gaps**

PRIORITY THEME	MAIN R&D INFORMATION GAPS
Seeds and seedlings	Seed handling, drying, storage, and studies on natural longevity; Production during the nursery period, and on packaging
Vegetative propagation	Worrisome portfolio; no minimum data to start a production system through asexual reproduction
Genetic improvement	Information limited to some localities; scarcity in data on effective population size
Wood technology	Little studied for all the species in forest plantation
Plantation management	Rotation, thinning intensity, pruning, ecophysiology, growth models, effects of competition and facilitation between species *in consortiums*
Topo-climatic zoning	Complete gap of knowledge
Market for timber products	Unknown market for plantation species (small diameter)
Forestry policy and legislation	Lack of an independent and representative forest policy

4.3 Gaps in Forestry Policy and Legislation

The theme of public policy and legislation was discussed during the workshop in only one group. The following points were highlighted.

- Forests offer a wide variety of services and products, from timber products to cosmetics, food, active ingredients for disease treatment, cultural and historical values, biodiversity, and multiple ecosystem services including soil conservation and carbon sequestration. Nonetheless, forestry is still classified as a polluting activity under Brazilian legislation (Law no. 6,938 /1981)[1].

- Analysis of the environmental legal system showed that there is no legal impediment to the establishment of forests for economic or environmental purposes, for native or exotic species. But there are major barriers in the complex administrative procedures that create confusion regarding the law. There is no legal clarity regarding who is responsible for supervising the management of planted forests in Brazil because there has been an institutional gap since the elimination of the Brazilian Institute of Forest Development (IBDF) in 1989.

- The establishment of forests for economic purposes is covered by two legal provisions: Law 12,651 /2012[2], which deals with the mandatory conservation, and management of forests remnants on private farms, called Areas of Permanent Protection (APP) and Legal Reserves (LR), and the Agricultural Policy of Planted Forests (Decree no. 8,375 /2014)[3] which regulates silvicultural production. Special rules apply to the restoration of APPs (which on properties of up to four fiscal modules[4] may also be used for economic purposes) and Legal Reserve (which on all properties may also be used for economic purposes in addition to serving environmental functions). However, the rules are incomplete at the federal level and further regulated only by some states such as São Paulo State. In the case of reforestation with native species in areas of alternative use or areas not protected by law (i.e., areas outside APP, Legal Reserve and other restricted areas), bureaucratic procedures and non-digital records exist, and some regulations are in the process of being drafted.

Public policy and forestry legislation should recognize that forests are multifunctional and that forest restoration (especially in Legal Reserve) under the New Forest Law (Law No. 12,651 /2012) represents an economic opportunity and a means to increase the resilience of rural land. The following approaches should be pursued:

- Define goals, legal frameworks, instruments and agencies responsible for the forestry sector
- Propose the creation of a government structure to address forest policy and the instruments to encourage decentralized management, for example, of water resources management
- Focus on the market (necessary products and flows), rather than on production
- Work with the entire production chain to mitigate the risks of forest activity and provide additional benefits
- Organize hubs or clusters (local production arrangements) that may have different governance structures from the usual ones led by a large company.

5. DEVELOPING INVESTMENT SCENARIOS

5.1 Investment Goals and Time Horizons

To maximize the efficiency of investments in a pre-competitive R&D Platform, related themes were grouped: seeds and seedlings, vegetative propagation, genetic improvement, wood technology, plantation management (including nutrition, phytossanity, ecophysiology, plantation designs, thinning, arbuscular mycorrhizal interactions), topo-climatic zones, market for timber products, and forest policy and legislation. The main research goals for each of these themes and estimated timeframe to achieve them are presented in Table 7.

Table 7 | **Goals and Expected Timeframe for Research Themes Selected for Inclusion in a Pre-Competitive R&D Platform**

PRIORITY THEME	ESTIMATED TIME	MAIN GOALS
Seed and Seedlings	Short term (1 to 5 years)	Find existing areas already planted with selected species; identify seed-trees ("mother trees") to harvest from restoration and conservation areas; establish conditions and alternative methods for quick quality analysis of seeds; initiate studies on phenology and reproductive biology for each of the 30 prioritized species.
	Medium to long term (10 to 20 years)	Develop storage methods for recalcitrant (unorthodox) species and those with low natural viability; develop seed processing equipment; adapt seed analysis laboratories to meet the demands of legalization; establish technical quality standards for seeds.
Vegetative propagation	Short to medium term (1 to 10 years)	Obtain selection of superior individuals for trunk form, average increment, and resistance to insect and diseases, considering genetic diversity.
Genetic improvement	Short term (1 to 5 years)	Select priority species for improvement, analysis and selection by current tests, *ex situ* conservation of base populations, testing of program species' progeny and/or origin, production of seeds by selection from seed harvesting areas, origin testing, progeny and cloning orchards testing, and preserve base populations.
	Medium term (5 to 10 years)	Continuous production of seeds with high genetic and physiological quality, conservation of genetic diversity, recurrent and reciprocal use of selection through progeny testing, *ex situ* preservation of base populations, installation of native clonal seed orchards in different regions of Brazil, and mass clonal production of superior trees.
	Long term (20 years)	Studies on the inheritance of wood characteristics, on association of quantitative traits and *loci* genetic markers, geomorphic studies, on the establishment of early blossoming and controlled crossings and the use of genetic markers to assist selection.
Wood technology	Short term (1 to 3 years)	Harvest samples of 30 native species from existing plantations for the technological characterization of samples older than 20 years.
	Medium to long term (10 to 20 years)	Monitor the wood properties per species, in every management test implemented by the R&D Platform, considering different species arrangements and combinations, different intensities of thinning and pruning, and different genetic materials.
Plantation management	Short term (1 to 5 years)	Analyze growth curves of trees in experiments already implemented.
	Medium term (5-10 years)	Outline and implement new experimental areas, with known genetic material and standardized management techniques, in different regions of each biome.
	Long term (20 years)	Repeat medium-term goals, with improved genetic material, by early selection (5 years).
Topo-climatic zoning	Short term (1 to 5 years)	Perform the topo-climatic zoning of 30 forestry species that occur in the Atlantic Forest and Amazon.
Market for timber products	Short term (1 to 5 years)	Analyze the potential market for timber with small diameters (DBH* less than 30 cm).
Forestry Policy and Legislation	Short to medium term (1 to 10 years)	Review and disseminate scientific concepts and terminologies related to reforestation in rural properties; review the incompatibility between Climate Change Policy and Law no. 6,938/1981; regulate the restoration of permanent preservation areas and legal reserves, including the use of timber species; define and propose a single responsible institution to promote forest development; propose a National Forestry Policy, independent of the Agricultural and Livestock Policy.

*DBH = Diameter at breast height. Breast height is defined as a point around the trunk at 1.30 meters.

5.2 Four Investment Scenarios

Four investment scenarios were developed for this study to illustrate alternative pathways to establish an R&D Platform. Scenario variables were the number of species (14, 20 or 30), scale, biome and the investment horizon (10 or 20 years). A summary of the costs for the four scenarios is provided in Table 8. The investments required represent less than 0.05% of Brazilian R&D investments (MCTIC, 2019).

Scenario I was found to be the best scenario to support a new forest economy based on native species. A more detailed breakdown of the investment costs associated with Scenario I (30 species and 20 years) is provided in Appendix E. Appendix E does not include costs estimated for the forestry policy and legislation theme; these costs are shown in Table 8. The forestry policy and legislation theme costs are generated in periodic meetings for a maximum of two years and must be estimated according to the number of participants. For six meetings of two days each, with the participation of 10 people, a cost of BRL 153,000 was estimated for travel, accommodation, and meals.

Scenario I, with 30 species and a timeframe of 20 years, needs an investment of BRL 28.1 million (~USD 7.30 million, exchange rate at Mar. 07, 2019). However, reducing the timeframe to 10 years (Scenario II) decreases the investment to BRL 21.02 million (USD 5.46 million) or 75 percent of Scenario I.

Scenario III (10 years, 20 species, 333 ha), requires investment of only BRL 17.33 million (USD 4.50 million), or 82 percent of Scenario II. However, cost-benefit analysis shows that Scenario III is not necessarily preferable because the average investment per species is higher than in Scenario II.

Scenario IV (10 years, 14 species, 500 ha) requires the highest average investment per species and therefore the lowest cost-benefit.

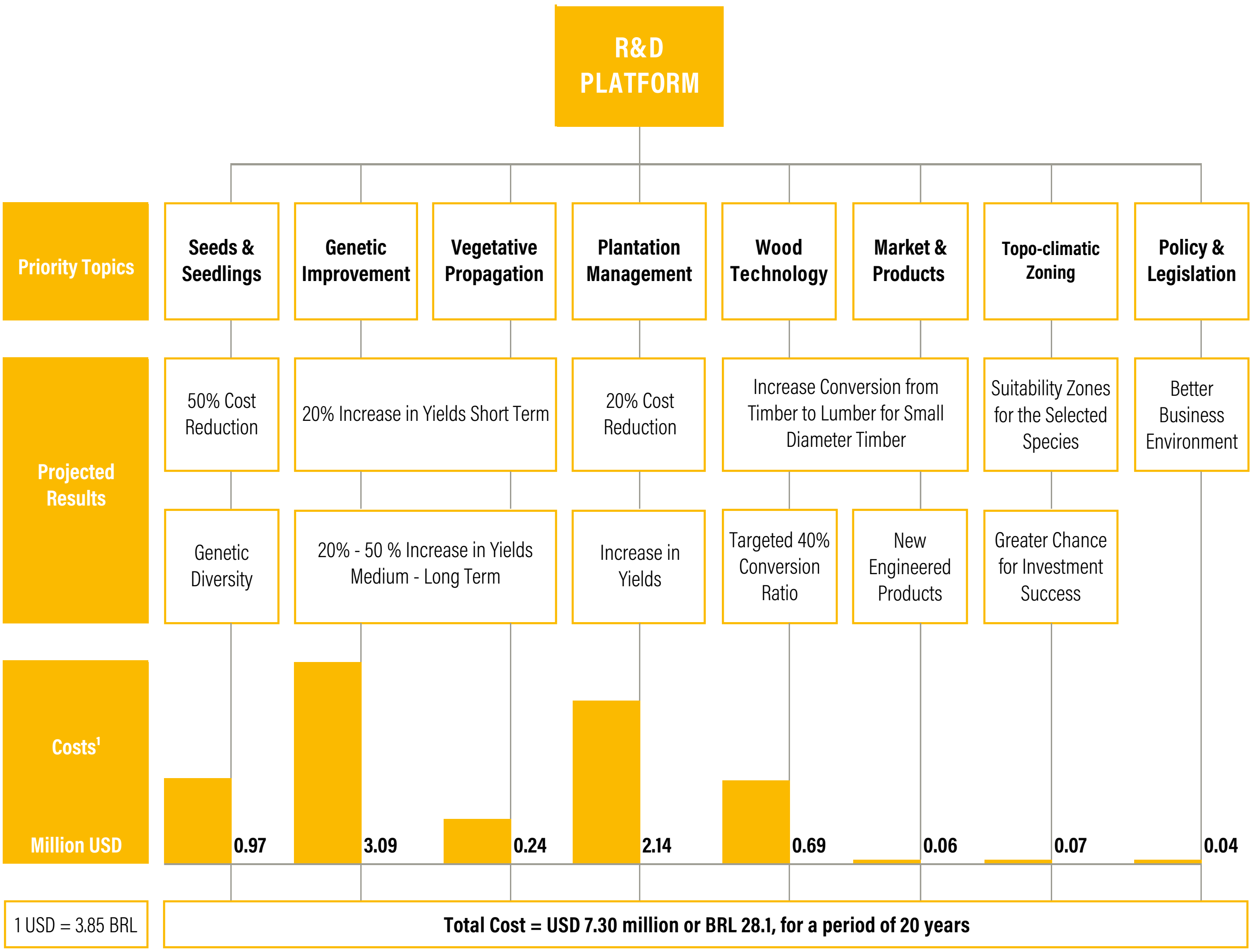
Table 8 | **Investment Required to Establish a Pre-Competitive R&D Platform under Four Scenarios**

	COST (BRL 1,000)			
SCENARIO	**I**	**II**	**III**	**IV**
Horizon (years)	20	10	10	10
Number of Species	30	30	20	14
Scale (hectares)	500	500	333	500
Theme				
Seed and Seedling Technology	3,734	3,206	2,720	2,227
Genetic improvement	11,893	8,365	5,800	4,230
Wood Technology	2,652	2,124	1,764	1,445
Topo-climatic Zoning	260	260	260	260
Plantation Management	8,252	5,724	5,444	5,075
Vegetative Propagation	941	941	941	941
Market for timber products	250	250	250	*250*
Policy and Legislation	*153*	*153*	*153*	*153*
TOTAL (BRL 1,000.00)	**28,135**	**21,023**	**17,332**	**14,581**
Average per Species (BRL 1,000.00)	**938**	**701**	**867**	**1,041**

5.3 Potential Benefits and Optimum Scales of a Pre-Competitive R&D Platform

Figure 2 presents the economic and other results expected from pursuing a pre-competitive R&D Platform for silviculture with native tree species in the Amazon and Atlantic Forest biomes under Scenario I.

Figure 2 | **Expected Results and the Investment Need to Establish a Pre-Competitive R&D Platform Based on Scenario I (30 Species in a Period of 20 Years)**



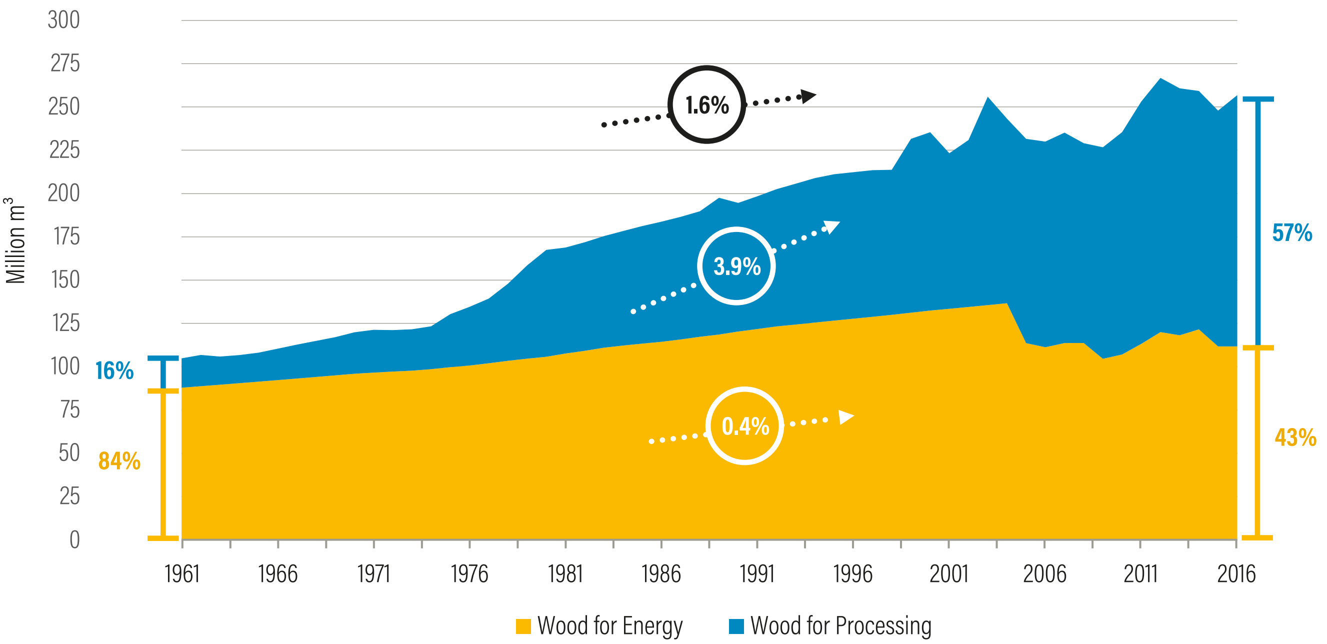
Note: The investment; exchange rate at Mar. 07, 2019. The investment per species is BRL 0.942 million (USD 0.244 million). The genetic improvement and plantation management programs account for 70% of total investment.

5.4 Global and Brazilian Timber Markets

Currently, institutional investments in mainstream reforestation represent an industry of USD 100 billion in the United States alone (New Forests 2015). In Brazil, investment is estimated at USD 35 billion and the average volume of roundwood produced is close to 250 million cubic meters (m^3) per year, from 1961 to 2016 (Figure 3). During the period 1961–2016, demand for timber increased 140 percent, from 100 million m^3 to 250 million m^3. In recent years, all timber production in Brazil has shifted away from wood for energy toward industrial roundwood. As a result, the source of wood has shifted somewhat from natural forests to planted forests. Many factors could explain this shift, but perhaps the most important is the increased competitiveness of planted forests, mostly due to research and development and fiscal incentives.

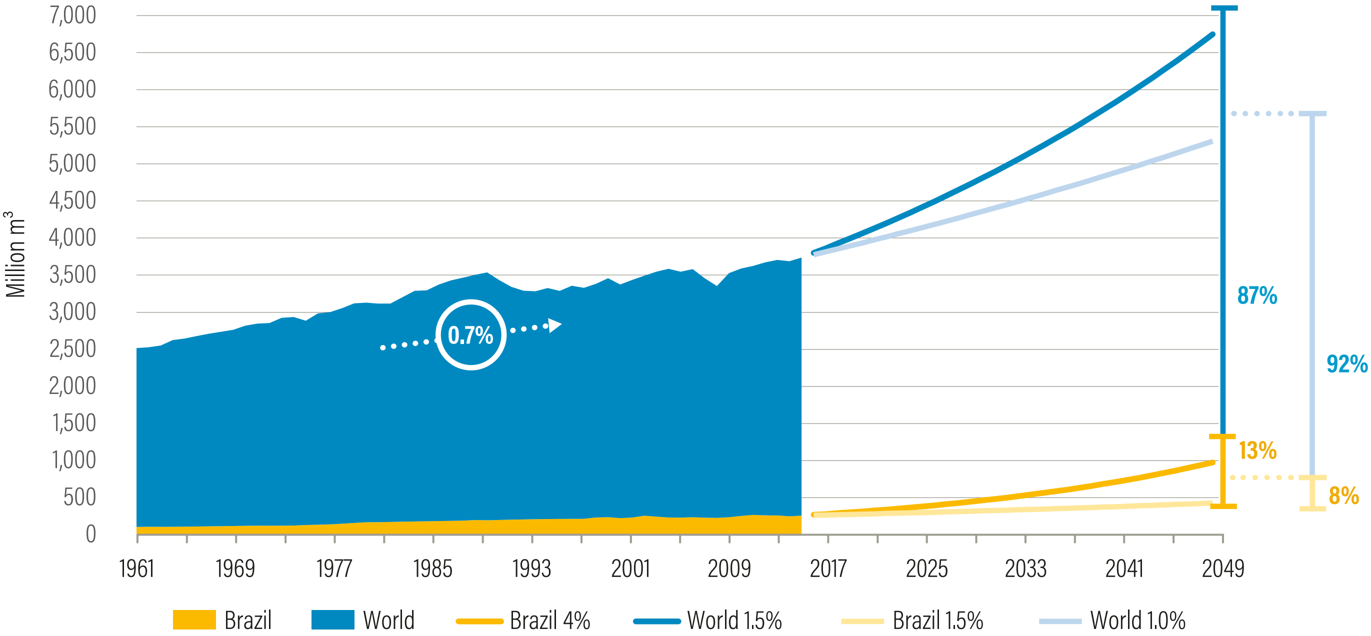
Despite the size of the mainstream reforestation industry, investment in native tree species is close to zero. According to FAOstat (2017), of the 3.9 billion ha of forests that cover nearly one-third of the world's land area, only 264 Mha are planted forests. To meet the growing demand for timber, an additional 100 Mha of forest plantations may be needed by 2050 to produce 2 billion m^3 of roundwood per year, compared with current production of 1.5 billion m^3 per year.
These figures are based on business as usual, which assumes a 1.5 percent increase in the demand for wood. This level of growth would lead to a demand for 7 billion m^3 of wood per year in 2050 (WBCSD 2015) (Figure 4).

Figure 3 | **Production and Uses of Wood in Brazil, 1961–2016**



Note: Growth rates in CAGR (compound annual growth rate). Overall compound annual growth rate was 1.6% per year over the last 55 years.
Source: FAOstat (2017), and IBGE (2017); elaborated by authors.

Figure 4 | **Past and Projected Growth in Demand for Timber**



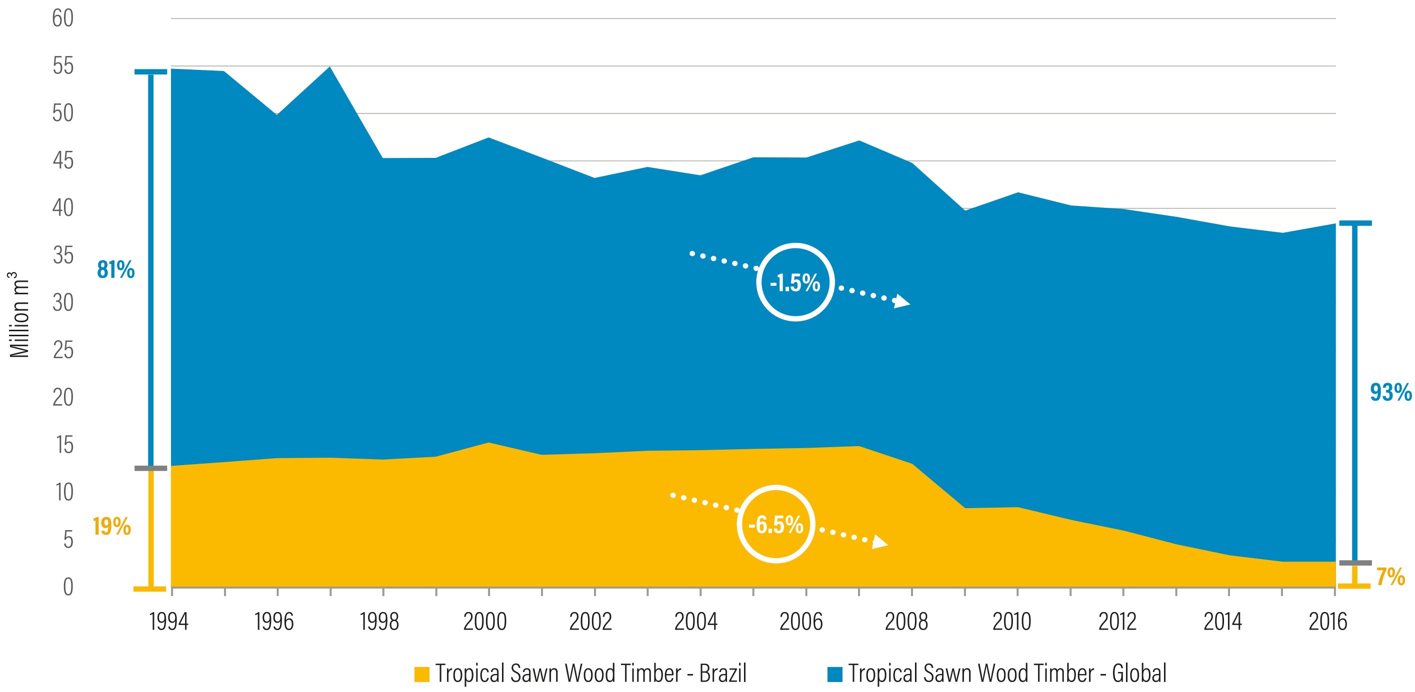
Note: Rates in CAGR (Compound Annual Growth Rate).
Sources: Historical data from FAOstat and ITTO, modified by authors. Projections based on scenarios from WWF Forest Living Report (2014), New Forests (2015), WBCSD (2015), and FSC and Indufor (2012); elaborated by authors.

Under a low-carbon economy scenario (Compound Annual Growth Rate–CAGR = 4%), Brazil could be producing 1 billion m³ of timber per year by the year 2050 and supply 13 percent of world's timber. Under business as usual, Brazil (CAGR = 1.5%) would produce close to 500 million m³ per year by 2050 and supply 8 percent of the world's timber, compared to 250 million m³ per year to date.

Tropical tree species face great uncertainty on the demand side due to illegal cutting and sale of timber. It is estimated that 50 percent of tropical timber traded in the world is illegally harvested; in the case of wood from the Brazilian Amazon the proportion could reach 70 percent.

Another uncertainty factor is the global economy. Sawn wood production from the Brazilian Amazon fell by 300 percent over the last 22 years (Figure 5). Globally, the reduction in the production of tropical sawn wood was 39 percent over the same period. Brazil's share of global production fell from 19 percent to 7 percent. Since the beginning of the financial crisis in November 2008, timber production has declined dramatically. The overall trend is therefore a declining supply of tropical timber over the last 20 years.

Figure 5 | **Tropical Sawn Wood Production Globally and in Brazil, 1994-2016**

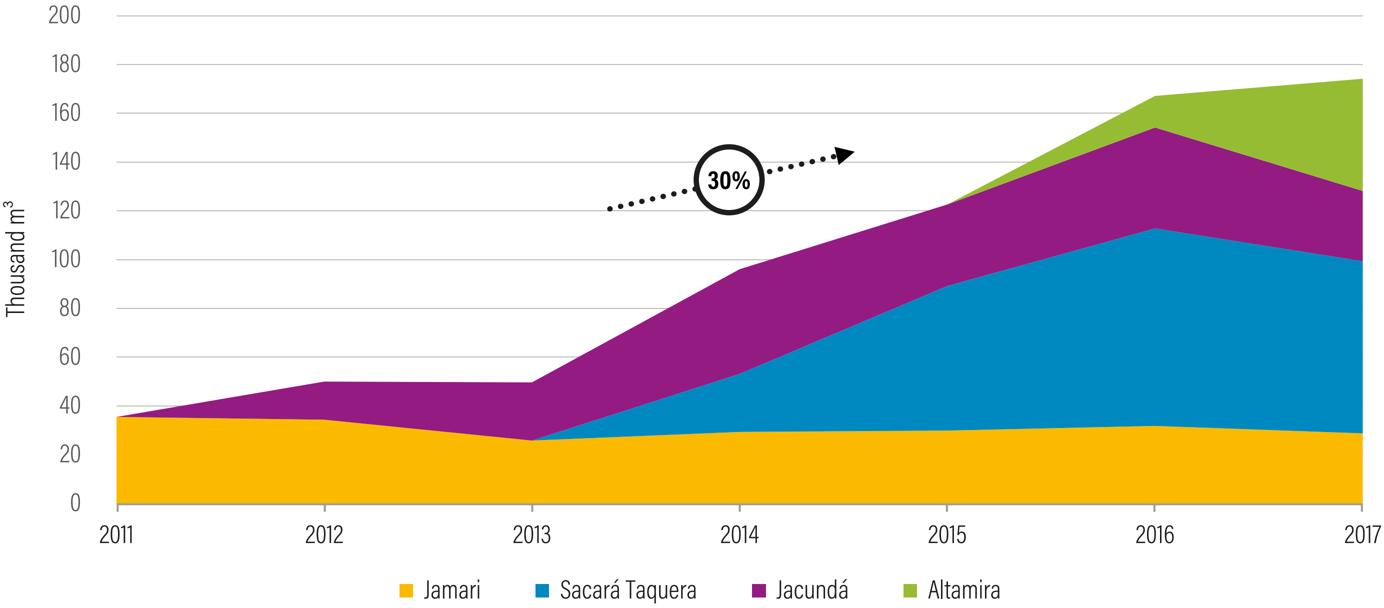


Despite having the largest rainforest in the world, Brazil supplies less than 10 percent of tropical timber production. Reasons for this disproportionate share include the following:

- Complex procedures and lack of due diligence to determine the legality of timber
- Low efficiency in the manufacturing process, with typical conversion rates of 20 percent
- Competition from low-cost illegal timber
- Substitution by other products

Given the historical pattern of timber production and its future drivers, it is fair to assume that sustainable management of natural forests and silviculture of native tropical timber species will supply the demand for tropical sawn wood. According to the Brazilian Forest Service (SFB 2018), the current output of roundwood is 174,000 m^3 under four concessions of natural forests in the Amazon (Figure 6).

Figure 6 | **Roundwood Production from Forest Concessions in Brazil, 2011–2017**



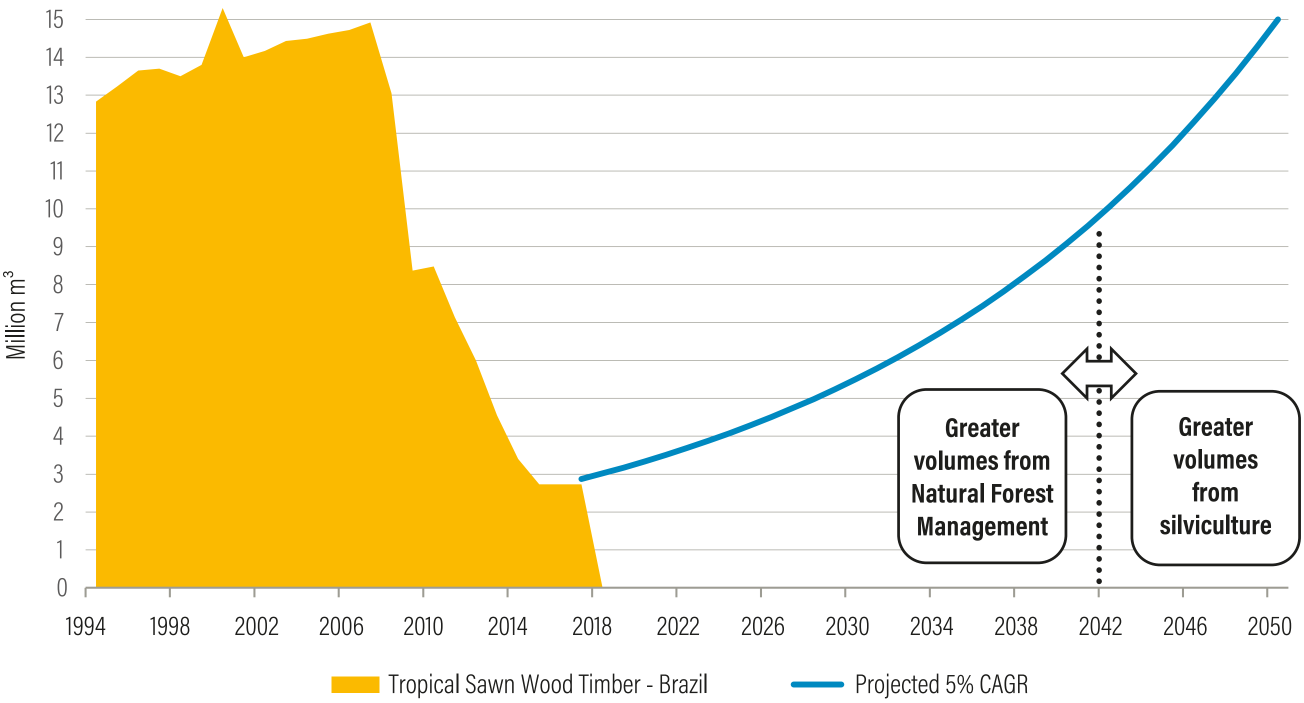
Note: Compound annual growth rate of production in the concessions was 30%, increasing from 35,000 m^3 to 174,000 m^3 between 2011 and 2017.
Source: adapted from SFB 2018.

However, the output of sawn wood from these concessions was, on average, only 61,000 m^3 per year over the period, resulting from a conversion rate of 35 percent (rate established by the National Council for the Environment - Conama 474/2016)[5]. This represents 2.2 percent of total sawn wood production in Brazil. The production of tropical sawn wood from silviculture of tropical native species is virtually zero to date.

This brief review illustrates the enormous challenge facing tropical natural forests, and highlights the opportunity to produce wood from native tree species in silvicultural systems and in forest concessions. However, to develop a new tropical forest economy, it is necessary to combat the illegal timber trade because it is impossible to compete in a market so distorted by tax evasion, cheap labor, unsustainable harvest practices, and timber prices defined by illegal loggers who represent 70 percent of the market (BVRio 2016). Civil society, the private sector, and academia are currently engaged in several activities to eliminate the illegal timber trade through the Brazilian Coalition on Climate, Forests and Agriculture.

Based on observed trends, it is possible that demand for sawn wood will rise at an average annual compound growth rate of 5.1 percent until 2050. We can expect an increasing share of production to be supplied from new forest concessions and plantations (Figure 7).

Figure 7 | **Past and Projected Trends in Brazil's Production of Sawn Wood, 1994–2050**



Note: Under this scenario, with a conversion rate from timber to lumber of 35%, production of roundwood could reach 43 million m³ per year by 2050.
Source: elaborated by authors.

Because of the long rotation cycles required for high-quality timber production, the greatest volume of timber will be supplied after about 25 years, when trees reach a diameter of 30 to 40 cm. The potential timber yield from silviculture of native tropical timber species is 5 million m³ of sawn wood, based on a 35 percent conversion of 14 million m³ of roundwood timber. From previous experience of the VERENA project (Batista et al. 2017), and from the yield curves described by Rolim and Piotto (2018), silviculture with native timber species can yield a mean annual increment of 10 m³/ha/year of roundwood, on 25- to 30-year rotation cycles. This level of production would require approximately 1.4 Mha of silviculture of native species.

This scale of production is highly sensitive to the assumptions underlying the scenario: conversion rate from timber to lumber; yields; share of timber production between natural forest management and silviculture; rate of substitution of wood products; and level of incentives to move toward a low-carbon economy.

However, this scenario may be viewed as a baseline that depends on future development of forest concessions and natural forest management in Brazil. In summary, silviculture with native species for timber production could contribute to at least 10 percent of Brazil's restoration target in Brazilian NDC, and without distorting the global market for tropical timber.

5.5 Estimating the Benefits of Investment in an R&D Platform

This section examines the viability of investing in a pre-competitive R&D Platform based on the thematic areas proposed in the study. The results expected from business-as-usual production (baseline) are compared with those expected given the benefit of greater research into silviculture of native tree species, with a focus on internal rates of return.

5.5.1 Returns: comparing the baseline with improved scenarios expected from the R&D Platform

The following estimates are based on the experience of Symbiosis Investments, a company that has already planted more than 560 ha in southern Bahia with a mix of 22 high-value timber species that are almost commercially extinct in the Atlantic Forest biome, and on the yields and models proposed by Rolim and Piotto (2018). The baseline scenario and returns were assessed using a discounted cash flow model proposed by Batista et al. (2017) (Table 9).

Table 9 | **Model Assumptions and Scenarios Based on Results Expected from the R&D Platform**

BASELINE

	ASSUMPTION	UNIT	MIX OF NATIVE SPP.	MIX EXOTIC & NATIVE
1	Rotation	Years	30	30
2	Capex	USD / ha	9,440.00	9,440.00
		BRL / ha	36,340.00	36,340.00
3	Land Lease	USD / ha	78.00	78.00
		BRL / ha / year	300.00	300.00
4	SG&A	USD / ha	91.00	91.00
		BRL / ha	350.00	350.00
5	Income Tax	%	34.00	34.00
6	Cost of Capital	%	9.00	9.00
7	Harvest & Mill Transport Costs	USD / m^3	12.00	12.00
		BRL / m^3	46.00	46.00
8	Conversion Costs	USD / m^3	39.00	39.00
		BRL / m^3	150.00	150.00
9	Freight and Customs Costs	USD / m^3 / km	0.04	0.04
		BRL / m^3 / km	0.14	0.14
10	Freight Distance	Atlantic Forest	300	300
		Amazon	2,000	2,000
11	MAI	m^3 / ha / year	9.6	18.5
12	Roundwood Output	m^3 at year 13	40.30	81.60
		m^3 at year 18		226.80
		m^3 at year 30	247.70	245.50
13	Conversion Rates Timber to Lumber	% at Thinning	20.00	20.00
		% at Final Cut	40.00	40.00
14	Timber Prices Native FOB	USD / m^3	780.00	780.00
		BRL / m^3	3,000.00	3,000.00
15	Timber Prices Exotic FOB	USD / m^3		415.00
		BRL / m^3		1,600.00
16	Timber Residue Price	USD / m^3	15.00	15.00
		BRL / m^3	60.00	60.00
17	Weighted Price [conversion x volume x price]	USD / m^3	312.00	218.00
		BRL / m^3	1,200.00	840.00
18	Real Increase in Sawnwood Timber Price	% CAGR	1.50	1.50
		Period Years	30	30
		Period Gain %	56.00	56.00

Note: The valuation of biological assets follows IFRS 13 standard. Numbers 1 to 18 are assumptions. International Financial Reporting Standards - defines fair value, sets out a framework for measuring fair value, and requires disclosures about fair value measurements.

SCENARIO WITH R&D

Cost Reduction (linked to 2 Capex)

Cost Reduction	20%	7,552.00
		29,072.00

Increase in Yields on Native spp. (linked to 11 MAI)

	I	II	III	IV
% CAGR	0.50	1.00	1.50	2.00
Period Years	30	30	30	30
Period Gain %	16	35	56	81

Likely Scenario

Increased Conversion Ratio (linked to 13 Conversion Rates)

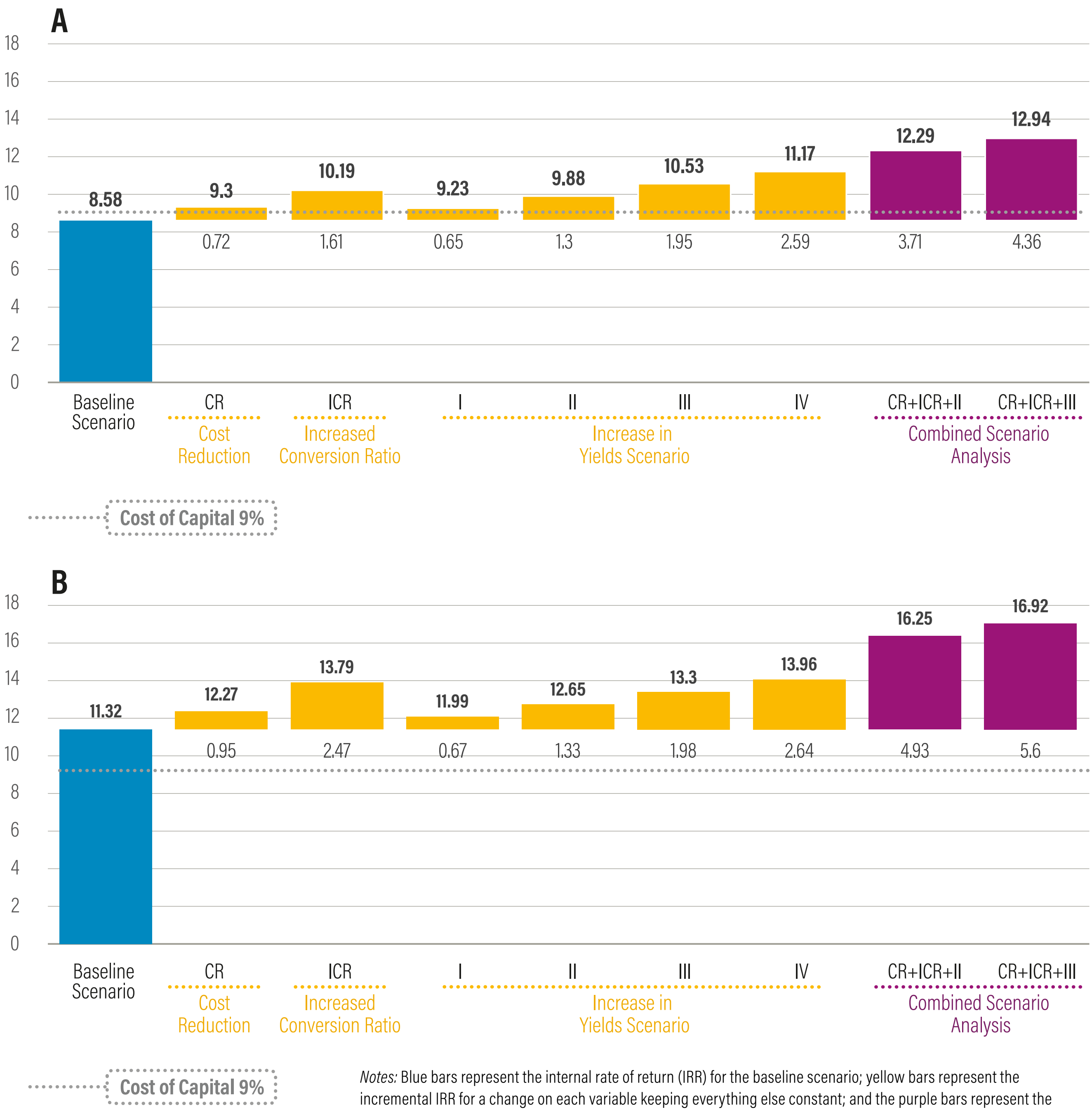
Increased Conversion Ratio	%	40
		50

1	Cycle based on growth curves by Rolim and Piotto 2018, and on the Symbiosis Investimentos model.
2	Capex based on the costs of Symbiosis Investiments, 44% of the Capex is spent in the first 4 years.
3	Based on opportunity costs for livestock land use, frequently converted into forests. Field research and FNP Agrianual, 2018
4	Based on a corporate administration team of project VERENA.
5	Tax on profit, in presumable profit regimen for corporations. It was presumed that products are exported with exemption of PIS, COFINS and ICMS.
6	Cost of capital based on CAPM and WACC models. For references see: www.wri.org/publication/verenainvestment-tool www.wri.org/publication/verenainvestment-tool
7	Based on semi-mechanized harvest system (chainsaw + forwarder), based on two experiences of the VERENA project.
8	Based on two experiences of project VERENA, costs are very sensitive to the sawn wood scale.
9, 10	Average shipping distance of 300 km until harbor for areas of the Atlantic Rainforest and of 2,000 km for projects in the Amazon. Cost / km / m^3 of shipping plus customs was of 0.14 BRL, based on two cases of project VERENA.
11, 12	Based on growth curves by Rolim and Piotto 2018, and on the Symbiosis Investiments model.
13	Based on conversion rates reported by Rolim and Piotto 2018
14	Based on historical price of jatobá sawn wood, CEPEA 2018 rates.
15	Based on historical price of eucalyptus sawn wood, CEPEA 2018 rates.
16	Based on historical price of eucalyptus process wood, CEPEA 2018 rates.
17	Mathematical formula.
18	Based on historical real price increase of: ipê, jatobá, peroba, eucalyptus sawn wood, CEPEA 2002 to 2018 rates.

Modeling analysis is based on four defined models, two for the Atlantic Forest and two for the Amazon: one with a mix of native species, and the other with a mix of exotic tropical species such as khaya (*Khaya senegalensis*) and toona (*Toona sinensis*). The most prominent difference between the models from the Amazon and Atlantic Forests is the freight distance—2,000 km and 300 km mean distance, respectively. It is important to highlight that in this analysis we considered plantations in areas of alternative land use, because native species, or a mix of native and exotic species, can be planted in Legal Reserves and Alternative Use Areas. As clearcutting was not considered in these models, the management would be the same for both soil uses.

Each of these scenarios was considered a baseline scenario (Figures 8 and 9), and the incremental rate of return was assessed for each variable (cost reduction; improved conversion ratio from timber to lumber; the increase in yield for scenarios I, II, III, and IV; and two scenarios combining these variables).

Figure 8 | **Internal Rate of Return (Percent) for Atlantic Forest Biome: A) mix of native species, B) mix native species and exotic tropical species**



Notes: Blue bars represent the internal rate of return (IRR) for the baseline scenario; yellow bars represent the incremental IRR for a change on each variable keeping everything else constant; and the purple bars represent the incremental IRR in the combined scenario, changing three variables at the same time keeping everything else constant.

Figure 9 | **Internal Rate of Return (Percent) Amazon Forest: A) mix of native spp., B) mix native species and exotic tropical species**

Notes: Blue bars represent the internal rate of return (IRR) for the baseline scenario; yellow bars represent the incremental IRR for a change on each variable, keeping everything else constant; and the purple bars represent the incremental IRR in the combined scenario, changing three variables at the same time and, keeping everything else constant.

None of these baseline scenarios with a mix of natives species, whether for the Atlantic Forest or the Amazon biome, meet the cost of capital, meaning that under the proposed assumptions the projects are not profitable.

In the case of the Atlantic Forest models, improvement in any one of the variables results in a profitable business. Under the scenario assuming a mix of native Atlantic Forest species and exotic species, the baseline scenario is already profitable and in the best-case scenario the internal rate of return (IRR) improves from 11.3 percent to 17 percent.

In the case of Amazon Forest models, freight costs penalize the model tremendously. Under both models in the Amazon, improved conversion ratio (ICR) and/or an increase in yields (Scenarios II, III, IV) result in a profitable business. A combination of cost reduction (CR), improved conversion ratio from timber to lumber (ICR), and increased yield caused IRR to rise from 8.2 percent to 14.5 percent in Scenario III.

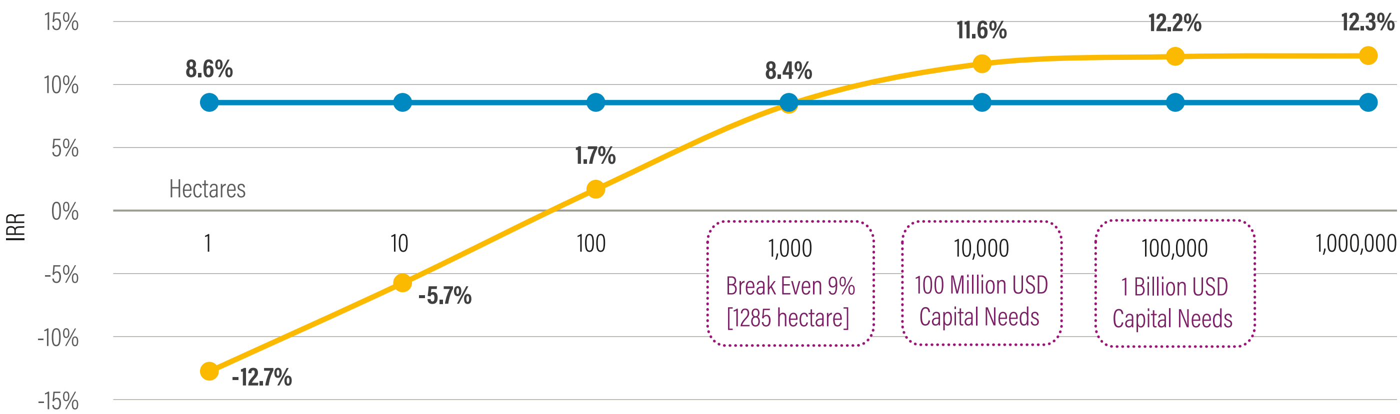
In the two models that included exotic species in the species mix, the ICR variable has the largest impact. This can be explained by the fact that models with exotic species yield higher timber volumes; improving the efficiency of conversion therefore maximizes the returns when compared to the lower yield models using a mix of native species only. This is the only variable that individually can make any of the four proposed models profitable (Atlantic Forest species mixed with exotic species is already profitable).

5.6 Scalability of an R&D Platform

To determine both the minimal and ideal scales of silviculture that would justify investment in an R&D Platform, we have used the Atlantic Forest model with a mix of native species, allowing all the other costs and revenues to vary with the scale, and keeping only the investment in R&D constant. The scenario chosen to compare against the baseline was the CR + ICR + II (20% reduction in costs; increased conversion ratio from 20% to 40% in thinning and from 40% to 50% in the final cut; and increase in yields of 35%). The scale varied from 1 ha to 1,000,000 hectares. The break-even scale to meet the cost of capital is 1,285 hectares (Figure 10).

Although the benefits of the economies of scale tend to infinity, there is a capital expenditure (capex) for silviculture implementation associated with the investments in R&D. As previously noted, the capex for R&D is fixed but the capex for silviculture implementation varies with the scale of planting. Although the rate of return at the scale of 100,000 ha is higher, the capital need is 1 billion USD, compared to 100 million USD at the scale of 10,000 ha. The baseline scenario is a straight line, because the investment and benefits in R&D are not included, thus leaving only variable costs.

Figure 10 | **Cost Benefit Analysis of Carbon Storage under Different Silvicultural Scenarios**



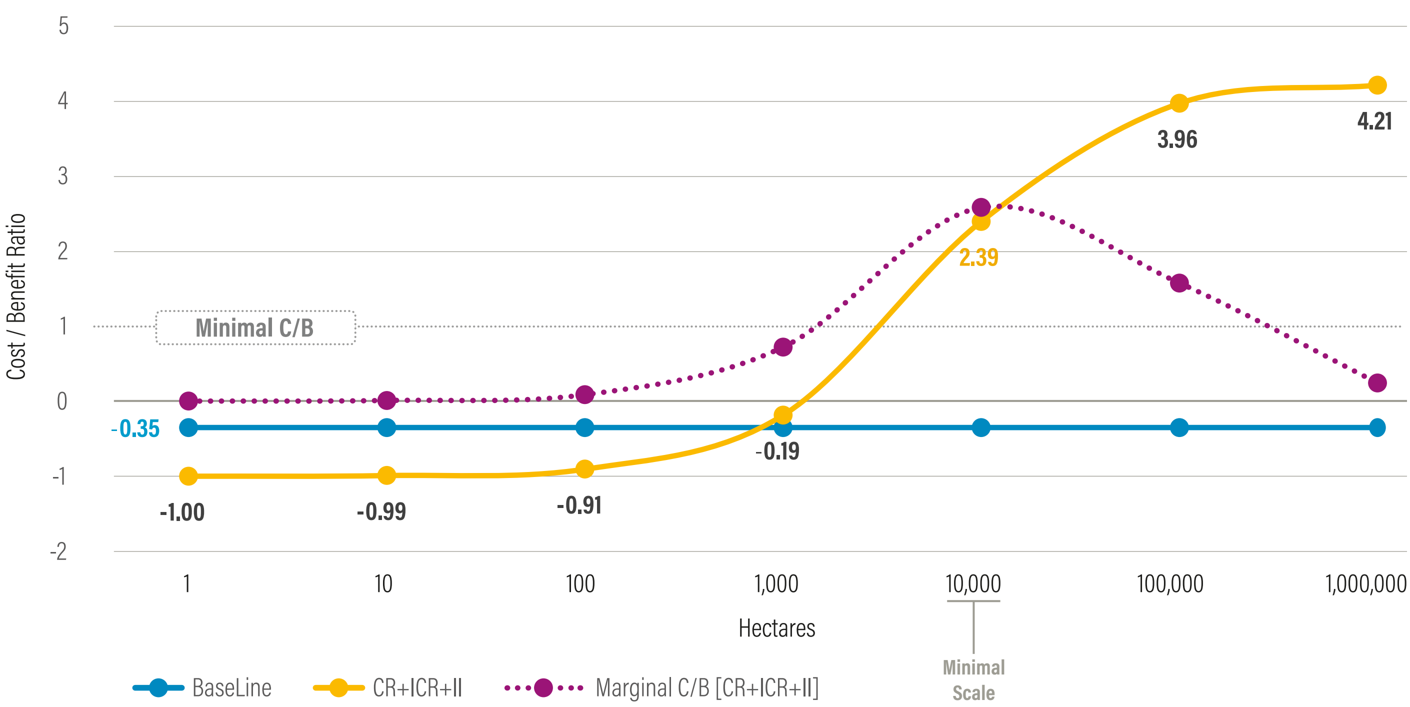
6. COST-BENEFIT ANALYSIS (CBA) OF THE INVESTMENT SCENARIOS

A Cost-Benefit Analysis (CBA) is an indicator used to measure the relationship between the costs spent on a given project, and the benefits it generates, in monetary or qualitative terms. The CBA, however, does not provide any sense of how much economic value will be created, which is shown in Figure 11. In the CBA we used the net present value (NPV, discounted at 9%) over the Capex of the initial outlay of investment in the forestry asset, for both baseline scenario and the improved scenario CR + ICR + II (20% reduction in costs; increased conversion ratio from 20% to 40% in thinning and from 40% to 50% in final cut; and increase in yields of 35%). The improved scenario also included the investment in R&D and its benefits (Figure 11).

If a project has a cost-benefit (CB) that is greater than 1, the project will deliver a positive NPV and will have an internal rate of return (IRR) above the discount rate used in the discounted cashflow (DCF) calculations. This suggests that the NPV of the project's cash flows outweighs the NPV of the costs, and the project should be considered. If the CB is equal to 1, the ratio indicates that the NPV of expected profits equal the costs. If a project's CB is less than 1, the project's costs outweigh the benefits and it should not be considered, which is the case for the baseline scenario.

In this case, the scenario CR + ICR + II showed a CB of 2.39 (tending to infinity), which indicates that the project's benefits significantly outweigh its costs. Moreover, **the proposed scenario of 10,000 hectares could expect USD 2.39 in benefits for each USD 1 of its cost** (7% capex in R&D and 93% forestry capex at outlay). By contrast, silviculture at the same scale under the baseline scenario yielded a loss of USD 0.35 for every USD 1 invested (100% forestry capex at outlay).

Figure 11 | **Cost-Benefit Analysis of Scale of Silviculture under Scenario CR + ICR + II**



Note: The cost-benefit ratio is the net present value/capex. The marginal cost-benefit was plotted to determine the most beneficial scale, since cost-benefit ratios tend to infinity.

6.1 CO_2 Removal

The average potential of native species to sequester and store carbon in biomass for a period of 30 years can reach 440 t CO_2e/ha (Rolim and Piotto 2018), i.e., the total stock in biomass reached in the 30th year. Considering that soils under forest have great potential to store carbon in depth (Marques et al. 2016), the potential of forestry with native species to store and sequester carbon is very high.

As before, the CBA was calculated using the capex at initial outlay and the scale of the platform. In this analysis, we have assessed the four growth scenarios and estimated the cost per ton of carbon stored, compared with the baseline scenarios (Figure 12). The assumptions underlying these scenarios are shown in Table 10.

Figure 12 | **Cost Benefit Analysis of Carbon Storage under Different Silvicultural Scenarios**

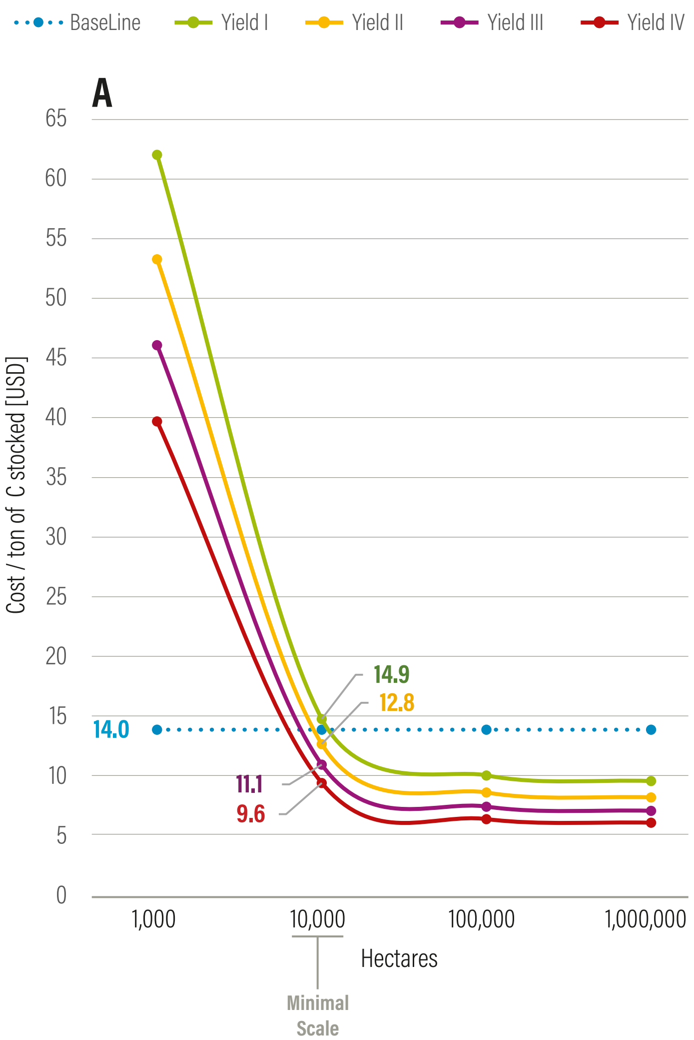


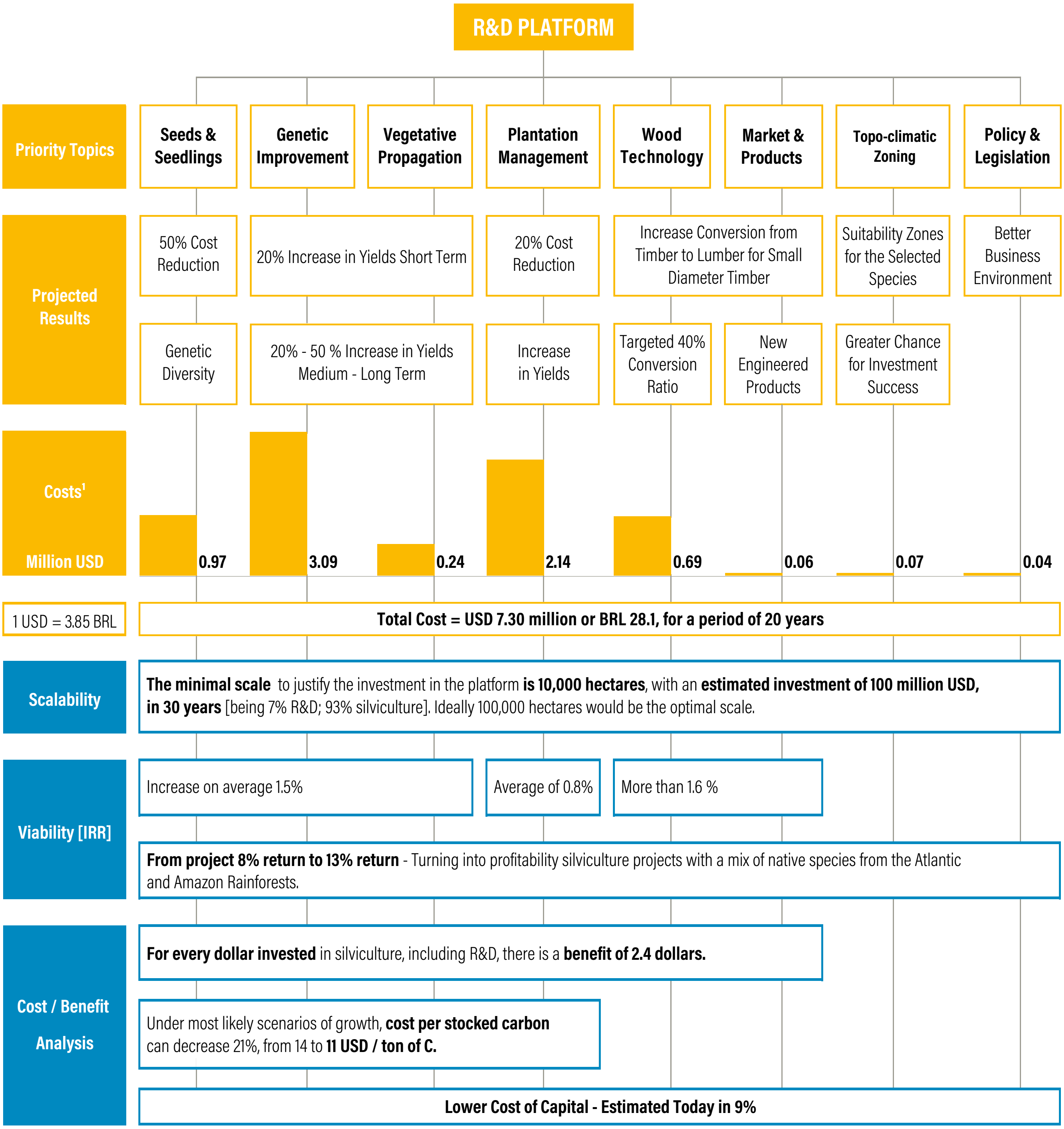
Table 10 | **Input Assumptions Used in Cost-Benefit Analysis**

SCENARIO	BASELINE	I	II	III	IV
Yield Increase (%)	0	16	35	56	81
Carbon Stored (tonnes/ha)	120	139	162	187	217

Source: elaborated by authors.

Scenarios II, III, and IV provide a better cost-benefit ratio than the baseline scenario at a scale of 10,000 hectares and above. Under the most likely scenarios, the cost per ton of carbon stored for scenarios II and III would decrease from 9 percent to 21 percent, respectively (baseline scenario of 14 USD per metric ton), at the scale of 10,000 hectares. This would improve further at the scale of 100,000 hectares, with the cost falling to less than USD 8.00 per ton of stored carbon. According to the report published by Forest Trends (2017), the average price of CO_2e for tree planting trade was USD 7.50. This means that carbon markets could subsidize the initial outlay costs of projects involving silviculture with native species. One caveat is that uncertainties remain over the wood density of trees grown more rapidly under improved growth scenarios, which could possibly lower the carbon storage potential. The overall results of the cost-benefit analysis are shown in Figure 13.

Figure 13 | **Input Assumptions Used in Cost-Benefit Analysis**



Note: Exchange rate at Mar. 07, 2019

7. CONCLUSIONS

There are many challenges to accelerate and scale up forest restoration and reforestation in Brazil, and a promising option is silviculture with native tree species. Planting native trees not only brings significant benefits in terms of climate change mitigation and adaptation, but also contributes to biodiversity conservation, financial benefits to farmers, and economic benefits to the country.

But a new forestry economy depends on a nationally integrated Research and Development (R&D) Platform for native species, with the goal of increasing scientific and technological knowledge, improving the productivity of species and the quality of the wood produced, and reducing costs. This platform must start through a pre-competitive arrangement that involves researchers, farmers, forest companies, investors, and government.

The results presented in this Working Paper show that there are gaps in knowledge for most native species in the timber market. A total of 30 species were prioritized for the pre-competitive R&D Platform and eight research themes were defined to address the gaps. The estimated time to fill most of the gaps within those themes is less than five years. One of the scenarios selected for the cost benefit analysis (CBA) includes eight themes, 30 species and a research program of 20 years. The investment required to establish a pre-competitive R&D Platform for this scenario is BRL 28,134,800.00 (~USD 7.30 million, exchange rate 05/09/2019).

Four models were used to estimate the scalability and conduct the cost-benefit analysis, two for the Atlantic Forest and two for the Amazon biome. The major difference between the biomes is the freight distance to ports. The mix of native and exotic species proved to be profitable in the Atlantic Forest biome because the exotic species already incorporate the gains from decades of investment in R&D that has resulted in a more efficient management system and higher yields. An increase of 35 percent in yield is enough to make all models profitable. The scenario using a yield increase of between 35 percent and 56 percent appears to be the most promising scenario. Although there is enormous potential to increase the scale of silviculture of native species to millions of hectares to supply the global demand for tropical timber and to a continuous increase rate of 1% per year, planting at a scale as small as 10,000 hectares would already justify an investment in the R&D Platform.

The economic advantages of silviculture with native species are that it offers a product that is becoming scarce in the market and will tend to increase in price in the future as the world moves towards a low-carbon economy. These trends will transform silviculture with native species into a long-term profitable business and investment.

An R&D Platform has the potential to increase the scale of silviculture with native species by providing attractive financial returns to investors and farmers. In the case of Brazil, this renewed interest in native species silviculture may not only answer the demands of the timber market, but also brings additional benefits including a decrease in deforestation and degradation, removal of millions of tons of CO_2 from the atmosphere, provision of green jobs and income, and reduced costs of restoration and reforestation.

Recommendations

- **Silviculture with native tree species needs to be recognized as an important strategy** to increase wood production and help Brazil achieve its NDC targets. Government agencies and the Brazilian Coalition on Climate, Forestry, and Agriculture need to promote and disseminate the importance of Brazilian native trees for agriculture and livestock production in integrated systems, their ability to increase the resilience of the agriculture sector and farmers, and their importance for job creation, income, carbon sink, and many other positive benefits.

- **A BRL 28 million fund should be created to be invested in a pre-**Competitive R&D Platform to start up silviculture with native species. Private sector investments in forest R&D reached about BRL 45 M in 2016, concentrated mainly in eucalyptus and pine, which occupied more than 90% of the area planted with forests in 2015 (IBÁ 2017). Five-year planning led by the forestry sector is one way to provide the up-front investments to start the pre-competitive platform suggested in this Working Paper. Grants from national and international organizations should also invest in a pre-competitive platform. Research institutions would contribute with their knowledge, human resources, and infrastructure as a counterpart to building the R&D Platform and sharing the benefits.

- **Brazil needs to reformulate its Forestry Legislation in order to boost silviculture with native species.** The forestry sector, research institutions, Federal (Ministries of Agriculture, Livestock and Supply, Finance, Environment), State and Municipal Governments need to join efforts to reformulate legislation to address the main bottlenecks and create incentives to boost silviculture with native species.

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APPENDIX A. WORKSHOP PARTICIPANTS

Table A1 | **Working groups, their thematic areas and participants at the "Gap and Priority Map of Research on Silviculture with Native Species" Workshop, held September 3–5, 2018, at the National Forest of Ipanema (Flona Ipanema), in Iperó, São Paulo State**

GROUP	THEMATIC AREA	PARTICIPATION	RESEARCHER	INSTITUTION
1	Seeds	Coordinator	Marcia Balistiero Figliolia	Atlantic Forest Seed Network (REMAS)
	Seeds	Collaborator	Fatima C.M. Piña-Rodrigues	Federal University of São Carlos (UFSCar)
	Seedlings	Coordinator	José Mauro Santana da Silva	Federal University of São Carlos (UFSCar)
	Seedlings	Collaborator	Lausanne Soraya de Almeida	Federal University of São Carlos (UFSCar)
	Vegetative propagation	Coordinator	Gilvano Ebling Brondani	Federal University of Lavras (UFLA)
	Vegetative propagation	Collaborator	Leandro Silva de Oliveira	Federal University of Minas Gerais (UFMG)
	Genetic improvement	Coordinator	Miguel Luiz Menezes Freitas	São Paulo Forestry Institute (IF)
	Genetic improvement	Collaborator	Ananda Virginia de Aguiar	Embrapa Forestry
	Genetic improvement	Coordinator	Andrei Caíque Pires Nunes	Federal University of Southern Bahia (UFSB)
2	Ecophysiology	Coordinator	Otávio Camargo Campoe	Federal University of Santa Catarina (UFSC)
	Ecophysiology	Collaborator	Marcelo Schramm Mielke	State University of Santa Cruz (UESC)
	Ecophysiology	Collaborator	Ândrea Carla Dalmolin	Federal University of Southern Bahia (UFSB)
	Mycorrhizal and Rhizobium	Coordinator	Sérgio Miana de Faria	Embrapa Agrobiology
	Plantation Management	Coordinator	José Cambuim	São Paulo State University (Unesp-Ilha Solteira)
	Plantation Management	Collaborator	Rafael de Paiva Salomão	Emílio Goeldi Paraense Museum
3	Wood technology	Coordinator	Alexandre M. de Carvalho	Federal Rural University of Rio de Janeiro (UFRRJ)
	Wood technology	Collaborator	João Vicente F. Latorraca	Federal Rural University of Rio de Janeiro (UFRRJ)
	Wood technology	Collaborator	Franciane Andrade de Pádua	Federal University of São Carlos (UFSCar)
	Forestry zoning	Coordinator	Silvio Brienza Junior	Embrapa Western Amazon
	Forestry zoning	Collaborator	Lucieta Guerreiro Martorano	Embrapa Western Amazon
	Forestry zoning	Collaborator	Maricélia Gonçalves Barbosa	Instituto Iniciativa Amazônia (INIAMA)
	Production modelling	Coordinator	Daniel Piotto	Federal University of Southern Bahia (UFSB)
	Benefits and Carbon	Coordinator	Samir Gonçalves Rolim	Amplo - Project Management
4	Economy and market	Coordinator	José de Arimatéia Silva	Federal Rural University of Rio de Janeiro (UFRRJ)
	Economy and market	Collaborator	Erich Schaitza	Embrapa Forestry
	Economy and Public Policies	Collaborator	Alan Batista	World Resources Institute - Brazil
	Public Policies and Legislation	Coordinator	Maria José Brito Zakia	Institute of Forest Research and Studies (IPEF)
	Public Policies and Legislation	Collaborator	Natália Guerin	Luiz de Queiroz College of Agriculture (ESALQ)
	Public Policies and Legislation	Collaborator	Hellen Patrícia Pecchi Leite	Luiz de Queiroz College of Agriculture (ESALQ)
	All topics	Special Guest	Vera Lex Engel	São Paulo State University (Unesp-Botucatu)
	All topics	Special Guest	Antônio Paulo Mendes Galvão	Former Director of Embrapa Forestry
	All topics	Special Guest	Renata Evangelista de Oliveira	Federal University of São Carlos (UFSCar)
	All topics	Special Guest	Ivan Crespo da Silva	Federal University of Paraná (UFPR)
	All topics	Special Guest	Rachel Biderman	World Resources Institute - Brazil

APPENDIX B. NATIVE TREE SPECIES CONSIDERED AT THE WORKSHOP

Table B1 | **List of 45 pre-selected native species used during the "Gap and Priority Map of Research on Forestry with Native Species" Workshop, held September 3-5, 2018, at the National Forest of Ipanema (Flona Ipanema) in Iperó, São Paulo State**

SCIENTIFIC NAME	COMMON NAME	FAMILY NAME	CLASS
BIOME ATLANTIC FOREST			
Araucaria angustifolia (Bertol.) Kuntze	araucária	Araucariaceae	1A
Astronium graveolens Jacq.	aderne	Anacardiaceae	1A
Balfourodendron riedelianum (Engl.) Engl.	pau-marfim	Rutaceae	1A
Calophyllum brasiliense Cambess.	guanandi	Calophyllaceae	1A
Cariniana legalis (Mart.) Kuntze	jequitibá	Lecythidaceae	1A
Cordia trichotoma (Vell.) Arráb. ex Steud.	louro-pardo	Boraginaceae	1A
Dalbergia nigra (Vell.) Allemão ex Benth.	jacarandá-da-bahia	Fabaceae	1A
Hymenaea courbaril L.*	jatobá	Fabaceae	1A
Peltophorum dubium (Spreng.) Taub.	canafístula	Fabaceae	1A
Plathymenia reticulata Benth.	vinhático	Fabaceae	1A
Simarouba amara Aubl.*	caixeta	Simaroubaceae	1A
Handroanthus serratifolius (Vahl) S.Grose	ipê amarelo	Bignoniaceae	1B
Lecythis pisonis Cambess.*	sapucaia	Lecythidaceae	1B
Manilkara subsericea (Mart.) Dubard	paraju	Sapotaceae	1B
Myracrodruon urundeuva Allemão	aroeira do sertão	Anacardiaceae	1B
Paubrasilia echinata (Lam.) Gagnon, H.C.Lima and G.P.Lewis	pau-brasil	Fabaceae	1B
Terminalia argentea Mart.*	capitão do campo	Combretaceae	1B
Terminalia mameluco Pickel	capitão do campo 2	Combretaceae	1B
Zeyheria tuberculosa (Vell.) Bureau ex Verl.	ipê felpudo	Bignoniaceae	1B
Anadenanthera peregrina var. *falcata* (Benth.) Altschul	angico	Fabaceae	2
Cedrela fissilis Vell.*	cedro rosa	Meliaceae	2
Copaifera langsdorffii Desf.	copaíba	Fabaceae	2
Joannesia princeps Vell.	boleira	Euphorbiaceae	3
Myrocarpus frondosus Allemão	cabreúva	Fabaceae	2
Pterigota brasiliensis (All.) K.Schum.	farinha seca	Malvaceae	3
Schizolobium parahyba (Vell.) Blake	guapuruvu	Fabaceae	3
BIOME CERRADO			
Dipteryx alata Vogel	Baru	Fabaceae	1 (NTFP)
BIOME AMAZON			
Bagassa guianensis Aubl.	tatajuba	Moraceae	1A
Bertholletia excelsa Bonpl.	castanha-do-pará	Lecythidaceae	1A
Carapa guianensis Aubl.	andiroba	Meliaceae	1A
Ceiba pentandra (L.) Gaertn.	sumaúma	Malvaceae	1A
Cordia goeldiana Huber.	freijó cinza	Boraginaceae	1A
Jacaranda copaia (Aubl.) D.Don	parapará	Bignoniaceae	1A
Schefflera morototoni (Aubl.) Maguire et al.	morototó	Araliaceae	1A
Schizolobium parahyba var. *amazonicum* (Huber ex Ducke) Barneby	paricá	Fabaceae	1A
Virola surinamensis (Rol. ex Rottb.) Warb.	ucuúba	Myristicaceae	1A
Vochysia maxima Ducke	quaruba verdadeira	Vochysiaceae	1A
Aspidosperma album (Vahl) Benoist ex Pichon	araracanga	Apocynaceae	1B
Dipteryx odorata (Aubl.) Willd.	cumaru	Fabaceae	1B
Vataireopsis speciosa Ducke	fava amargosa	Fabaceae	1B
Couma utilis (Mart.) Müll.Arg.	sorva	Apocynaceae	2
Enterolobium maximum Ducke	fava timbaúva	Fabaceae	2
Swietenia macrophylla King	mahogany	Meliaceae	2
Parkia gigantocarpa Ducke	fava bolota	Fabaceae	3
Tachigali vulgaris L.G.Silva and H.C.Lima	taxi-branco	Fabaceae	3

* Species common to the Atlantic Forest and the Amazon Forest. NTFP = non-timber forest product. The baru (*Dipteryx alata*) produces a nut that is traded in the Cerrado region, and has excellent quality of timber.

APPENDIX C. RESEARCH GAPS AND PRIORITIES INDICATED BY NUMBER OF LITERATURE CITATIONS

Table C1 | **SEEDS. The table shows the number of research citations for selected variables relating to seeds**

TREE SPECIES	THEMES (# OF CITATIONS)									
	SEEDS/ KG	ORIGIN	SEED HAN-DLING	HAR-VEST	DRYING	STO-RAGE	LIFES-PAN	GERMI-NATION	DOR-MANCY	TOTAL
Araucaria angustifolia	1	9	3	4	1	5	2	2	2	29
Astronium graveolens	2	1	1	2	1	1	-	2	1	11
Balfourodendron riedelianum	4	6	3	5	3	4	3	4	4	36
Berthollethia excelsa	1	4	3	3	-	3	2	4	2	22
Calophyllum brasiliense	2	6	6	6	3	3	1	6	4	37
Carapa guianensis	4	8	4	7	4	3	1	6	3	40
Cariniana legalis	1	1	1	1	1	1	-	1	-	7
Ceiba pentandra	2	2	1	2	1	2	1	3	1	15
Cordia goeldiana	1	3	2	1	2	4	3	5	-	21
Cordia trichotoma	3	5	2	4	1	2	3	6	2	28
Dalbergia nigra	3	8	5	7	2	8	4	9	2	48
Dipteryx odorata	1	1	-	1	2	-	-	3	-	8
Handroanthus serratifolius	2	3	2	-	1	1	2	3	1	15
Hymenaea courbaril	5	8	4	5	3	2	-	7	7	41
Jacaranda copaia	2	4	1	4	2	2	2	4	1	22
Lecythis Pisonis	3	2	2	1	1	1	1	2	-	13
Manilkara subsericea	-	2	-	1	-	-	-	2	1	6
Myracrodruon urundeuva	1	5	2	4	2	3	2	7	2	28
Paubrasilia echinata	1	4	1	3	2	2	1	4	-	18
Peltophorum dubium	2	13	4	2	3	2	-	8	13	47
Plathymenia reticulata	2	4	2	6	2	1	2	6	6	31
Schefflera morototoni	2	2	1	1	-	-	-	2	2	10
Simarouba amara	1	1	-	1	-	-	-	-	-	3
Terminalia argentea	3	4	2	4	-	2	1	4	2	22
Vataireopsis speciosa	-	1	-	1	-	-	-	-	-	2
Virola surinamensis	1	4	1	2	-	2	3	4	3	20
Vochysia maxima	-	1	-	1	-	-	-	-	1	3
Zeyheria tuberculosa	2	1	-	2	-	2	2	2	1	12
Total	**52**	**113**	**53**	**81**	**37**	**56**	**36**	**106**	**61**	**595**

- indicates no citations found

Table C2 | **SEEDLINGS. The table shows the number of research citations for selected variables relating to seedlings**

TREE SPECIES	THEMES (# OF CITATIONS)					
	FERTILIZATION	SHADING	CYCLE	PACKAGING	SUBSTRATE	TOTAL
Araucaria angustifolia	1	4	-	-	-	5
Astronium graveolens	-	1	-	1	-	2
Balfourodendron riedelianum	-	2	-	-	-	2
Berthollethia excelsa	3	1	-	-	1	5
Calophyllum brasiliense	1	6	-	3	3	13
Carapa guianensis	2	2	-	1	1	6
Cariniana legalis	2	2	1	-	1	6
Ceiba pentandra	1	1	1	1	-	4
Cordia goeldiana	2	1	-	-	1	4
Cordia trichotoma	1	4	-	4	1	10
Dalbergia nigra	4	3	-	-	-	7
Dipteryx odorata	-	1	-	-	3	4
Handroanthus serratifolius	1	1	-	-	-	2
Hymenaea courbaril	5	6	-	4	3	18
Jacaranda copaia	-	5	-	-	-	5
Myracrodruon urundeuva	3	1	1	1	3	9
Peltophorum dubium	7	1	1	4	-	13
Plathymenia reticulata	1	-	-	-	2	3
Simarouba amara	-	2	1	-	-	3
Virola surinamensis	-	2	1	-	-	3
Vochysia maxima	1		1	-	-	2
Zeyheria tuberculosa	-	1	2	1	-	4
Total	**35**	**47**	**9**	**20**	**19**	**130**

Table C3 | **VEGETATIVE PROPAGATION. The table shows the number of research citations for selected variables relating to vegetative propagation.**

TREE SPECIES	THEMES (# OF CITATIONS)							
	PROPAGATION TYPE	PROPAGULE SOURCE	SHADING	FERTILIZATION	CYCLE	SUBSTRATE	PACKAGING	TOTAL
Araucaria angustifolia	10	10	6	3	9	7	9	54
Bertholletia excelsa	1	1	1	-	1	1	1	6
Calophyllum brasiliense	4	4	4	-	4	4	3	23
Carapa guianensis	1	1	1	-	1	1	1	6
Cedrela fissilis	4	4	4	2	4	4	4	26
Copaifera langsdorffii	2	2	2	1	2	2	2	13
Cordia trichotoma	4	4	4	1	4	4	4	25
Dalbergia nigra	3	3	3	-	3	3	1	16
Handroanthus serratifolius	2	2	2	-	2	2	2	12
Hymenaea courbaril	1	1	1	-	1	1		5
Myracrodruon urundeuva	1	1	1	-	1	1	1	6
Peltophorum dubium	4	4	4	-	4	4	4	24
Plathymenia reticulata	1	1	1	-	1	1	1	6
Schizolobium parahyba var. *amazonicum*	1	1	1	1	1	1	1	7
Schizolobium parahyba	1	1	1	-	1	1	1	6
Swietenia macrophylla	7	7	7	-	5	7	7	40
Total	**47**	**47**	**43**	**8**	**44**	**44**	**42**	**275**

Table C4 | **GENETIC IMPROVEMENT. The table shows the number of research citations for selected variables relating to genetic improvement**

TREE SPECIES	THEMES (# OF CITATIONS)										
	ORIGIN	AGE	MAI		CV (%)		AVERAGE HERITABILITY		NE	SUR-VIVAL	TOTAL
			H (M)	DBH (CM)	H	DBH	H	DBH			
Anadenanthera peregrina var. *falcata*	2	2	2	2	2		2				12
Araucaria angustifolia	28	28	26	12	7	10	5	5	4	5	130
Balfourodendron riedelianum	24	24	23	19	24	18	22	18	18	24	214
Paubrasilia echinate	1	1	-	-	-	-	-	-	1	-	3
Cariniana legalis	25	25	25	19	24	18	25	19	1	25	206
Cordia trichotoma	1	1	-	-	1	1	1	1	-	1	7
Hymenaea courbaril	2		-	-	-	-	-	-	2	-	4
Myracrodruon urundeuva	35	36	16	25	29	32	29	33	12	21	268
Peltophorum dubium	37	37	36	31	36	34	30	26	2	35	304
Schizolobium parahyba var. *amazonicum*	8	8	8	8	4	4	-	-	-	8	48
Schizolobium parahyba		5	-	-	5	3	5	3	-	1	22
Terminalia argentea	4	5	-	-	1	1	5	5	1	5	27
Virola surinamensis	13	13	12	12	-	-	1	1	-	12	64
Zeyheria tuberculosa	1	1	1	-	-	-	-	-	-	-	3
Total	**181**	**186**	**149**	**128**	**133**	**121**	**125**	**111**	**41**	**137**	**1312**

Notes: - indicates not found; MAI = mean annual increment; H = height, in meters; DBH = diameter at breast height, in centimeters;
CV = coefficient of variation, in percentage; Ne = number of effective size.

Table C5 | **WOOD TECHNOLOGY. The table shows the number of research citations for selected variables relating to wood technology**

TREE SPECIES	THEMES (# OF CITATIONS)						
	DRYING	SPLITTING	RESISTANCE	DENSITY	USES	PROCES-SING	TOTAL
Araucaria angustifolia	2	1	1	2	-	1	7
Astronium graveolens	1	-	1	2	1	1	6
Bagassa guianensis		-	-	1	1	-	2
Balfourodendron riedelianum		-	-	1		-	1
Pterigota brasiliensis	1	-	1	1	1	1	5
Carapa guianensis		-	-	1	-	-	1
Cariniana legalis	1	-	1	3	1	1	7
Cedrela fissilis		-	-	1	-	-	1
Copaifera langsdorffii	1	-	1	1	1	1	5
Cordia trichotoma	1	-	1	1	1	1	5
Dalbergia nigra	1	-	1	1	1	1	5
Dipteryx odorata		-	-	1	-	-	1
Handroanthus serratifolius	1	-	1	1	1	1	5
Hymenaea courbaril	2	1	2	2	-	1	8
Joannesia princeps	1	-	1	1	1	1	5
Lecythis Pisonis	1	-	1	1	1	1	5
Manilkara longifolia	1	-	1	1	1	1	5
Parkia gigantocarpa	1	-	1	1	-	-	3
Paubrasilia echinata	2	-	1	2	1	1	7
Peltophorum dubium	2	1	3	4	-	1	11
Schizolobium parahyba var. *amazonicum*	1	-	4	4		-	9
Schizolobium parahyba	2	-	1	2	1	-	6
Swietenia macrophylla	2	-	2	2		-	6
Tachigali vulgaris	2	-	2	2	2	1	9
Terminalia mameluco	1	-	1	1	1	1	5
Zeyheria tuberculosa	1	-	1	1	1	1	5
Total	**28**	**3**	**29**	**41**	**17**	**17**	**135**

Table C6 | **PLANTATION MANAGEMENT. The table shows the number of research citations for selected variables relating to forest management**

TREE SPECIES	THEMES (# OF CITATIONS)						
	SPACING	SOIL PREP	THINNING INTENSITY	PRUNING	CONSOR-TIUMS	ECOPHY-SIOLOGY	TOTAL
Anadenathera peregrina var. *falcata*	5	3	-	-	3	-	11
Araucaria angustifolia	21	4	4	-	1	-	30
Astronium graveolens	12	2	-	-	16	-	30
Bagassa guianensis	6	1	-	-	2	-	9
Balfourodendron riedelianum	14	3	-	-	16	-	33
Pterigota brasiliensis	1	1	-	-		-	2
Bertholletia excelsa	4	2	-	-	2	-	8
Calophyllum brasiliense	7	4	1	1	7	-	20
Carapa guianensis	6	2	-	-	2	-	10
Cariniana legalis	15	2	-	-	2	-	19
Cedrela fissilis	23	12	-	-	26	-	61
Copaifera langsdorffii	10	8	-	-	10	-	28
Cordia goeldiana	11	7	-	-	11	-	29
Cordia trichotoma	23	3	-	-	3	-	29
Dalbergia nigra	3		-	-	2	-	5
Dipteryx odorata	6	3	-	-	5	-	14
Genipa americana	4	3	-	-	3	-	10
Handroanthus serratifolius	4	2	-	-	3	-	9
Hymenaea courbaril	21	9	-	-	23	-	53
Jacaranda copaia	7	4	-	-	1	-	12
Joannesia princeps	4		-	-	3	-	7
Myracrodruon urundeuva	20	2	1	-	14	-	37
Myrocarpus frondosus	1		-	-		-	1
Paubrasilia echinate	1	1	-	-		-	2
Peltophorum dubium	34	10	-	-	13	-	57
Plathymenia reticulata	6		-	-	1	-	7
Schizolobium parahyba var. *amazonicum*	10	8	-	-	9	-	27
Schizolobium parahyba	24	6	-	-	10	-	40
Shefflera morototoni	3	3	-	-		-	6
Simarouba amara	2		-	-	2	-	4
Swietenia macrophylla	14	5	-	-	7	-	26
Tachigali vulgaris	3		-	-	1	-	4
Terminalia argentea	3	1	1	-	3	-	8
Virola surinamensis	1	1	-	-	1	-	3
Zeyheria tuberculosa	6	6	-		5	-	17
Total	**335**	**118**	**7**	**1**	**207**	**-**	**668**

Note: - indicates not found

Table C7 | **FOREST MODELING. The table shows the number of research citations for selected variables relating to forest modeling**

TREE SPECIES	THEMES (# OF CITATIONS)						
	AGE	VOLUME	EQ_HYPSO	EQ_VOLUME	EQ_ BIOMASS	FFORM	TOTAL
Araucaria angustifolia	1	-	1	-	-	-	2
Astronium graveolens	-	-	-	1	-	-	1
Bagassa guianensis	1	1	-	-	-	1	3
Balfourodendron riedelianum	1	-	1	1	-	-	3
Pterigota brasiliensis	1	-	1	1	-	-	3
Bertholettia excelsa	4	5	-	1	-	5	15
Carapa guianensis	3	4	-	2	-	4	13
Cariniana legalis	-	-	-	1	-	-	1
Copaifera langdsdorffii	-	1	-	1	-	-	2
Cordia goeldiana	3	3	-	-	-	3	9
Cordia trichotoma	1	-	-	-	-	1	2
Dipteryx odorata	1	2	-	1	-	1	5
Handroanthus serratifolius	4	1	2	1	-	2	10
Hymenaea courbaril	5	3	1	1	1	4	15
Jacaranda copaia	2	3	-	1	-	3	9
Lecythis Pisonis	1	-	1	2	-	-	4
Manilkara longifolia	1	2	-	3	-	1	7
Myracrodruon urundeuva	2	-	2	1	1	-	6
Plathymenia reticulata	-	-	-	-	1	-	1
Schefflera morototoni	1	2	-	1	2	2	8
Schizolobiium parahyba var. *amazonicum*	2	2	-	2	2	3	11
Schizolobium parahyba	-	-	-	1	-	-	1
Simarouba amara	1	-	-	1	1	1	4
Swietenia macrophylla	3	3	-	-	-	3	9
Tachigali vulgaris	3	4	-	1	-	4	12
Terminalia argentea	1	1	-	-	1	1	4
Virola surinamensis	1	1	-	-	-		2
Vochysia maxima	2	1	-	-	-	2	5
Zeyheria tuberculosa	1	-	1	1	-		3
Total	**46**	**39**	**10**	**25**	**9**	**41**	**170**

Note: - indicates not found; Eq_Hypso = Hypsometric Equation; Eq_Volume = Volume Equation; Eq_Biomass = Biomass Equation; FForm = Form Factor.

APPENDIX D. SYMBIOTIC ASSOCIATION BETWEEN MICROORGANISMS AND NATIVE TREE SPECIES

Table D1 | **Species that present rhizobia nodulation and/or mycorrhization**

SPECIES	RHIZOBIA NODULATION	MYCORRIZHATION
Anadenanthera peregrina var. *falcata*	X	X
Araucaria angustifolia		X
Aspidosperma album		
Astronium graveolens		X
Bagassa guianensis		
Balfourodendron riedelianum		
Basiloxylon brasiliensis		
Berthollethia excelsa		
Calophyllum brasiliense		X
Carapa guianensis		X
Cariniana legalis		X
Cedrela fissilis		X
Ceiba pentandra		X
Copaifera langsdorffii		X
Cordia goeldiana		X
Cordia trichotoma		X
Couma utilis		
Dalbergia nigra	X	X
Dipteryx alata		X
Dipteryx odorata		X
Enterolobium maximum	X	
Handroanthus serratifolius		X
Hymenaea courbaril		X
Jacaranda copaia		X
Joannesia princeps		X
Lecythis pisonis		X
Manilkara longifolia		
Myracrodruon urundeuva		X
Myrocarpus frondosus		
Parkia gigantocarpa		
Paubrasilia echinata		
Peltophorum dubium		X
Plathymenia reticulata	X	X
Schefflera morototoni		X
Schizolobium parahyba		X
Schizolobium parahyba var. *amazonicum*		X
Simarouba amara		X
Swietenia macrophylla		X
Tachigali vulgaris	X	X
Terminalia argentea		
Terminalia mameluco		
Vataireopsis speciosa		
Virola surinamensis		X
Vochysia maxima		X
Zeyheria tuberculosa		X

APPENDIX E. INVESTMENT NEEDS TO IMPLEMENT R&D PLATFORM

The following tables detail the investments needed to implement an R&D Platform for forestry using native tree species under Scenario I.

Table E1 | **Seed technology and production**

INVESTMENT NEEDS	COST (BRL)
Marking of matrices and harvesting of 30 species	255,000.00
Phenology and Reproductive Biology studies (with 20M and 10D P&D grants, 5 to 15 years)	1,776,000.00
Adjustment of 2 existing labs and improvement of equipment	400,000.00
Purchase of equipment, material and chemical products for 2 labs	150,000.00
Analysis and quality control of seeds of 30 species (15,000 seeds)	363,000.00
Certification processes and training according to the legislation to train multipliers in all biomes	350,000.00
Establishment of infrastructure and purchase of materials for the improvement, drying and conditioning of seeds	140,000.00
Field trips (accommodation and meals)	300,000.00
TOTAL	**3,734,000.00**

Table E2 | **Genetic improvement**

INVESTMENT NEEDS	COST (BRL)
Marking of Matrices (30 species) (1 to 3 years)	255,000.00
Implementation of 300 ha (1 to 3 years) (30 ha per location)	3,000,000.00
Maintenance for 20 years	6,000,000.00
Permanent materials and Consumption (2 labs) (1 to 3 years)	562,000.00
Selection of the best materials (with 20M and 10D P&D grants, 5 to 20 years)	1,776,000.00
Field trips (accommodation and meals)	300,000.00
TOTAL	**11,893,000.00**

Table E3 | **Wood technology**

INVESTMENT NEEDS	COST (BRL)
Renovation of 2 labs (Wood Anatomy, Processing, Energy and Chemistry) (1 to 3 years)	400,000.00
Minimum equipment (1 to 3 years)	296,000.00
Collection and Quality analysis of wood in plantations and experiments (with 20M and 10D P&D grants, 1 to 20 years)	1,776,000.00
Field trips (accommodation and meals)	180,000.00
TOTAL	**2,652,000.00**

Table E4 | **Topo-climatic zoning of 30 native species**

INVESTMENT NEEDS	COST (BRL)
Consumable material	60,000.00
Permanent material	40,000.00
Data Collection and Analysis (with 4M P&D grants) (1 to 2 years)	144,000.00
Field trips (accommodation and meals)	16,000.00
TOTAL	**260,000.00**

Table E5 | **Management of native species *in consortium* (mixed) forestry systems**

INVESTMENT NEEDS	COST (BRL)
Implementation of 200 ha (1 to 3 years, 20 ha per location)	2,000,000.00
Maintenance for 20 years	4,000,000.00
Permanent material (2 labs) (1 to 3 years)	100,000.00
Consumable material for 10 years (2 labs)	76,000.00
Data Collection and Analysis in experiments (with 20M and 10D P&D grants, 5 to 20 years)	1,776,000.00
Field trips (accommodation and meals)	300,000.00
TOTAL	**8,252,000.00**

Table E6 | **Assessment of markets for wood products from native species**

INVESTMENT NEEDS	COST (BRL)
Data Collection and Analysis	150,000.00
Development of Product Prototypes	50,000.00
Field trips (accommodation and meals)	50,000.00
TOTAL	**250,000.00**

Table E7 | **Vegetative propagation of native species**

INVESTMENT NEEDS	COST (BRL)
Consumable and permanent material (2 labs)	150,000.00
Data Collection and Experiments (with 12M and 3D P&D grants, 1 to 10 years)	748,800.00
Field trips (accommodations and meals)	42,000.00
TOTAL	**940,800.00**

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