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Master's Thesis – Master Sustainable Business and Innovation

Sustainable Business Model Innovation for Eucalyptus plantation management in the Atlantic Forest – barriers and opportunities

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Abstract

Introduction: Radical deforestation of the Brazilian Atlantic Forest diminished it to only 7% of its original land cover. While natural forests continue shrinking, forest plantation areas are growing. These are represented mainly by Eucalyptus monocultures, providing only minimum ecosystem services and showing vulnerability towards climate change. Therefore, the first study objective was to explore economic and ecological aspects of alternative management approaches with enhanced ecosystem services provisioning compared to conventional Eucalyptus plantations. The second aim was to identify the barriers that need to be overcome for sustainable business model innovation through the implementation of these alternative management approaches in the pulp and paper industry.

Theory: This research follows a novel approach of applying transition theory for sustainable business model innovation. Laasch (2018) provides guidelines to analyse the current and potential innovative business models. The Technological Innovation System model from Hekkert et al. (2007) serves as the theoretical framework for the analysis of the barriers concerning business model innovation.

Methodology: An exploratory comparative case study design was chosen to examine the conventional business model and alternative Eucalyptus management approaches. Data was collected through literature research and 16 semi-structured interviews with stakeholders across the Eucalyptus supply chain that allowed drawing a holistic picture of the industry's barriers to business model innovation.

Results: Although showing improved provision of ecosystem services, alternative approaches lack short-term profitability compared to conventional Eucalyptus monocultures, which was the key hampering factor to innovation. Legitimacy for alternative approaches through pressure from pulp customers and society is missing, just as public policy support for long-term success is lacking. Furthermore, the market structure for alternative products and services from the studied alternative management approaches is still in its infancy.

Discussion and Conclusion: The research shows suitability for applying the TIS framework to explore innovation dynamics of business models. However, this study advises an explorative approach to the barrier analysis since influences of all system functions were discovered, whereas the Hekkert et al. (2011) suggested a selective focus on certain functions. Furthermore, the findings provide policy makers and practitioners with practical recommendations, such as introducing favourable tax schemes and subsidies to address the unequal level playing field and establishing partnerships within the industry to facilitate market establishment for alternative wood products and ecosystem services.

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1 Introduction

Once covering 100 million hectares of native forest, only 7% of natural rainforest remained in the Atlantic Forest biome, which is mainly located in the South-East of Brazil, *see Figure 1* (FAO & UNEP, 2020). The remaining fragmented patches of rainforest represent biodiversity hotspots, with 8% of the global plant species being unique to the region (Ribeiro et al., 2009). The radical deforestation started in the 20th century through land use transformation for economic activities focusing on agriculture, pasturelands, pinus and Eucalyptus plantations, and urban expansion (Souza, 2020).

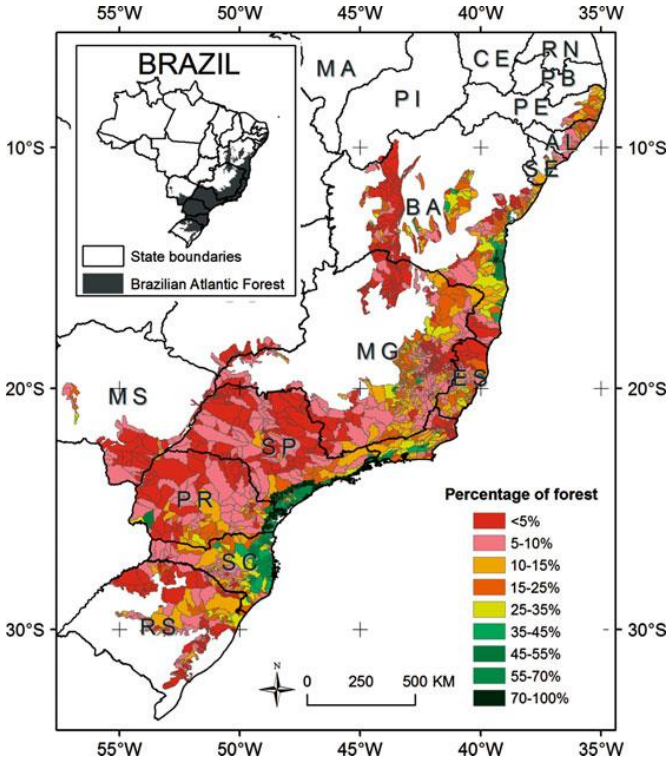

Figure 1: Forest cover of Atlantic Forest in Brazil (Ribeiro et al., 2011, p. 420)

While the worldwide natural forest areas are still shrinking, forest plantation areas continue growing (FAO & UNEP, 2020). Eucalyptus comprises 77% of the tree plantation area in Brazil, covering 6.97 million hectares in 2019 (IBA, 2020). Its wood is mainly used for pulp production in Brazil, and also serves as material for logs, sawn lumber, charcoal, fencing poles, and oil (IBA, 2018). Brazil's largest sustained Eucalyptus productions are based in the Atlantic Forest (Brancalion et al., 2020; FAO & UNEP, 2020). The vast majority (90%) of the plantations belongs to corporations and is primarily located in the states of Minas Gerais, São Paulo, and Mato Grasso do Sul (Kröger, 2014; Silva et al., 2020). The FAO and UNEP (2020, p. 16) define plantations as *"intensively managed forests, mainly composed of one or two tree species, native or exotic, of equal age, planted with regular spacing and mainly established for productive purposes"*. Eucalyptus plantations mostly represent intensively managed

monocultures with short rotation cycles of 5-7 years and are therefore preventing the natural regeneration of native plant species (Bremer & Farley, 2010).

Besides the negative impact on biodiversity, the general capacity of Eucalyptus monocultures to provide ecosystem goods and services is minimal (Bauhus et al., 2017; Lindenmayer et al., 2012). The United Nations initiated the Millennium Ecosystem Assessment in 2000 to emphasize the importance of ecosystem services for human well-being. The assessment was based on existing research and identified four ecosystem service groups. Accordingly, ecosystem services include provisioning services (e.g., timber, food, genetic resources), regulating services (e.g., water regulation, air purification), cultural services (e.g., eco-tourism, recreation), and supporting services (e.g., nutrient cycling, primary production). Through biodiversity loss, climate change, pollution, and land use change, more than 60% of global ecosystem services are deteriorating (Millennium Ecosystem Assessment, 2005). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reports that reductions in planted species diversity severely decrease the resilience of ecosystems against climate change, pests, and pathogens (IPBES, 2019). Short-rotation Eucalyptus monocultures provide wood products and sequester carbon, but other than that have significant negative effects on ecosystems (World Bank, 2017). The most severe impacts are decreasing biodiversity and high water consumption (Amazonas et al., 2018; World Bank, 2017). A shift towards more sustainable forest plantation management approaches is urgently needed for plantations to improve their performance in ecosystem services (Van Oorschot et al., 2016).

Tavares et al. (2019) recommend adapting Eucalyptus plantation management by creating a stand structure similar to historical ecosystems in the Atlantic Forest, mixing Eucalyptus with native species, allowing longer rotation periods, reducing the harvesting impact and pest control, and allowing the understory to grow. Bremer and Farley (2010) suggest a similar approach to improve biodiversity conservation in plantations and reach both environmental and economic targets of forest management. As land-use practices are still mainly driven by short-term financial profitability, a reasonable economic performance of potential alternatives with better ecosystem services provision (hereafter called “alternatives”) is key in driving the transition towards more sustainable forest management (Knoke & Huth, 2011). To scale up such a new forest plantation management system, it needs to be translated into an appropriate business model, which in turn needs to be made attractive to plantation owners (European Commission, 2018).

A business model explains how entrepreneurs create, deliver and capture value (Teece, 2010). Changing from monocultures to more environmentally sustainable options requires multiple business model components to adapt, as entrepreneurs offer a different value to their customers and change their key activities. This business model transformation can be framed as the process of sustainable

business model innovation (SBMI). While financial profitability is a crucial factor to be taken into account on the firm level (micro) of forest plantation business, the socio-economic environment enables or hampers alternatives to be scaled up on system level (macro). Important factors influencing the industry include governmental regulations, voluntary market standards and consumer behaviour (Brancalion et al., 2012; Stubbs & Cocklin, 2008). Barriers to SBMI can be of organisational and socioeconomic origin and can be classified as 'soft' and 'hard'. Soft barriers refer to social and institutional factors such as cultural values and regulations, whereas hard barriers reflect financial and technical factors such as lack of training and infrastructure (De Jesus & Mendonça, 2018).

In the current literature, many studies focus on the ecological impacts of monocultures and investigate governance options to promote the provision of ecosystem services in forestry (Van den Berg et al., 2013). Meijaard et al. (2011), for example, conducted research on opportunities and barriers for ecosystem services certification. However, the authors state that their study is not to be confused with achieving sustainable management outcomes. Business model innovation in forestry has been addressed by Lee and Chang (2019), whose aim was to understand how small-scale forest firms certified by FSC in Taiwan transform their conventional business models towards a more sustainable approach. There are multiple studies about the transition towards sustainable forest management (Angelstam et al., 2004), of which Arets and Veeneklaas (2014) also took the costs and benefits of sustainable tropical timber production into account.

However, to my best notice, there is no scientific research so far that analyses conventional and potential alternative Eucalyptus plantation management from a business model perspective, also studying barriers of the innovation system in the Atlantic Forest in Brazil. As the challenges for sustainable forest management vary widely among countries with different socio-economic circumstances and ecosystems (Angelstam et al., 2004), and impacts of plantations are highly context specific (Van den Berg et al., 2013), studies conducted in other countries with different ecosystems cannot be generalized. Therefore, this research identifies the barriers on the organisation and system level towards sustainably managed Eucalyptus plantations in the Atlantic Forest region. The precondition of the innovative business model was an improved provision of ecosystem services.

The following research questions will be answered through this research.

1. What are the public and private costs and benefits of a more sustainable Eucalyptus plantation business model in the Atlantic Forest when taking ecosystem services into account?
2. What are the soft and hard barriers on organisational and socioeconomic levels that need to be overcome for a successful sustainable business model innovation in Eucalyptus production?

To accomplish the aim of the study, a business model analysis was done for the cases of monoculture Eucalyptus plantations and three alternative management options, including economic aspects and ecological impacts of ecosystem services. After that, the barriers to SBMI by Laukkanen and Patala (2014) served as a basis for identifying blocking mechanisms through interviews with stakeholders of the Eucalyptus wood production industry. Finally, the barriers were connected to the Technological Innovation System (TIS) framework by Hekkert et al. (2007) to assess the functioning of the innovation system.

This study contributes to innovation sciences theory by analysing the current regime of Eucalyptus plantation management and potential disruptive alternatives both on a system level (macro) and firm level (micro). The inclusion of the micro level in the TIS framework allows drawing a holistic picture of the innovation system and thereby provides a novel approach to applying transition theory (Sarasini & Linder, 2018; Reike et al., 2017). Furthermore, the study broadens the focus of transition theory from entirely technological innovations to also recognising business models as subjects of innovation and being part of innovation system dynamics (Laukkanen & Patala, 2014). By providing detailed analyses of purely profit-driven and Sustainable Business Models embedded in the same context, this research contributes to a better understanding of their differences and the challenges of SBMI.

Both transition researchers and practitioners can profit from an assessment of current and new business model dynamics in the context of a heuristic view of system transformation (Sarasini & Linder, 2018). The resilience of forest plantations to droughts caused by climate change gains importance for the pulp and paper industry in the Atlantic Forest, asking for the exploration of new approaches (Amazonas et al., 2018). On a landscape level, alternative systems with mixed tree species or higher stand structure heterogeneity can provide more resources and shelter for native fauna, improve abiotic conditions and improve the resilience of the forest plantation itself, but also of its surroundings (Fahrig et al., 2011; Puettmann et al., 2015). Moreover, practitioners in the field can benefit from the financial cost and benefit evaluation of alternative and more sustainable approaches to Eucalyptus plantation management. By identifying barriers towards SBMI and proposing ways of how to overcome them, government agencies and other organisations could work on solutions to spur large-scale transition towards sustainable Eucalyptus plantation management.

The following chapters introduce the theoretical framework and literature review for the analysis, present the business model and barrier analysis results, discuss the findings, and give a final conclusion of the conducted research.

2 Theory

The following chapter introduces the theoretical framework, which serves as a guideline for the research analysis. It introduces the business model concept paired with sustainable innovation as well as transition theories. The literature review represents the systemic structure for an innovation system in the Eucalyptus plantation industry.

2.1 Theoretical Framework

2.1.1 Sustainable business model innovation

Innovative business models have the power to disrupt entire industries as individual firms influence the wider production and consumption system and drive the introduction of new products and technologies into the market. Thus, appropriate business models are essential to achieve systemic change (Boons & Lüdeke-Freund, 2013; Gambardella & McGahan, 2010). A business model describes how to create and deliver value for the customer, capture the value through payments and subsequently turn it into profit (Teece, 2010). Chesbrough (2002) defined six necessary components of a business model: describing the value proposition representing the value created for users; defining the targeted market; identifying the essential infrastructure for the value chain; estimating the revenue streams and cost structure; explaining the position of the company on the market taking competitors into account; and presenting the strategy for sustained competitive advantage.

The business model perspective allows identifying which aspects need to be changed at the micro level in order to successfully create sustainability values by integrating social, environmental and economic activities (Schaltegger et al., 2012). The approach of SBMI allows companies to rethink and redesign the purpose, value creation and organisation of the business to reach significant positive or decrease negative impacts on the society and/or environment (Bocken et al., 2014; Boons & Lüdeke-Freund, 2013). Stubbs and Cocklin (2008) propose to take into account stakeholder needs when designing a sustainable business model, thereby also considering nature and biodiversity impacts. Business models can be used as a market device for communication with relevant stakeholders to argue how the new entrepreneurial approach can become profitable (Boons & Lüdeke-Freund, 2013).

The integration of multiple business logics leads to heterogeneous business models. Business logics shape how organisations *"produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality"* and allows them to be conceptualised (Thornton & Ocasio, 1999, p. 804). Sustainable business models, for example, combine social, environmental and economic value logics which all determine how the business operates (Laasch, 2018). In contrast, commercial businesses are defined by focusing on a single business logic, which is exchanging value for making financial profit in a competitive market. Laasch (2018) stated questions for the four main business

logics that can help to identify and define different homogeneous (one business logic, financial profit driven business model) and potential heterogeneous business models (multiple business logics, e.g., sustainable business models) (see Table 1).

Table 1: Guiding questions to identify business model (Laasch, 2018, pp. 164–165)

Business logics	Questions to identify business model
Value Proposition	What kind of value does the organisation offer to whom?
Value Creation	How does the organisation create value?
Value Exchange	How does the organisation exchange value?
Value Capture	How is the value created by an organisation captured?

2.1.2 Transition theory and barriers for sustainable business model innovation

The success of an SBMI is mainly dependent on the regime of the socioeconomic system it operates in. If the system does not support sustainable behaviour, structural and cultural changes are needed on the system level (Laukkanen & Patala, 2014; Stubbs & Cocklin, 2008). Transition theories can be applied to study sustainable transformation in systems. However, Schaltegger et al. (2016, p. 271) addressed that besides few pioneering attempts, *"no consistent theoretical framework is available that connects business models with the dynamics of markets, industries, or society and that helps understand the dynamic role of business model innovation for sustainability transformations of markets"*.

There are four main transition theories (Sarasini & Linder, 2018). First, the Multi-Level Perspective (MLP) by Geels (2002) describes dynamics of systemic transition being influenced by three heuristic levels: niches, socio-technical regimes, and socio-technical landscapes. Second and third, theories of strategic niche management (Kemp et al., 1998) and large technical systems (Bijker et al., 1987) focus on the macro level and miss out on the contributions of innovating actors on the micro level, as does the MLP theory mentioned before (Farla et al., 2012). Fourth, the Technological Innovation System (TIS) by Hekkert et al. (2007) presents a set of key functions (*see Table* 3) that are essential for well-performing innovation systems. The functioning of innovation systems is influenced by elements whose presence and capacities are crucial to the emergence of innovations. These are framed as the four-fold structure of the TIS, consisting of actors, institutions, interactions and infrastructure (Wieczorek & Hekkert, 2012). For an innovation to flourish, all seven TIS functions need to perform well. However, throughout the development stages of innovation, some functions are more relevant to spur diffusion than others, asking for a determination of the development phase before assessing the TIS functions (*Figure* 2) (Hekkert et al., 2011).

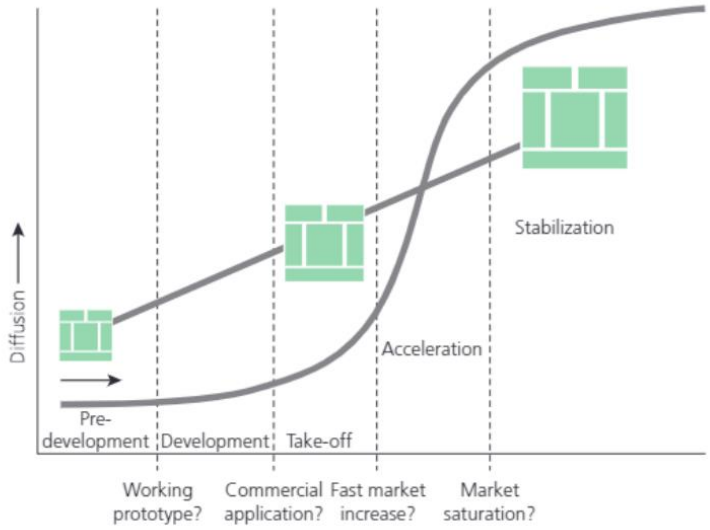

Figure 2: Phase of development for innovations (reprinted from Hekkert et al., 2011, p.9)

So far, transition theories have focused primarily on technical systems such as energy supply or transportation (Sarasini & Linder, 2018). However, Amit and Zott (2012) argue that social technologies need more attention in innovation and transition theories, as they enable the implementation of physical technologies. Furthermore, since social technologies are defined as adding or changing activities in a business, they are tightly connected to SBMI (Laukkanen & Patala, 2014).

Laukkanen and Patala (2014) show that transition theory can be linked to business model innovation by extending the TIS framework with business model theory. Reike et al. (2017) also suggest applying the TIS model to complement the firm level perspective with its external networks. Hence, TIS was also used in this research to identify potential inertia within the societal and socio-technical system of business innovation.

For the TIS analysis, Laukkanen and Patala (2014) suggest first identifying soft and hard barriers for SBMI. These barriers to the diffusion of sustainable business models can be grouped into three categories: Regulatory barriers; Market and Financial barriers; and Behavioural and Social barriers *(see Table 2).* Second, they explained those can be overcome through analysing and improving the functions of the innovation systems framework (Hekkert et al., 2007; Laukkanen & Patala, 2014). The functions of the TIS framework are explained in *Table 3*, also showing how the original TIS framework can be adapted to SBMI.

Table 2: Barriers for SBMI (Laukkanen & Patala, 2014, p. 13)

Barrier groups for SBMI	**Barriers**
Regulatory barriers	- Lack of long-term legal, regulatory frameworks - Inconsistent and overlapping regulatory mechanisms - Operational environment stability (regulatory risks) - Lack of encouragement to innovativeness - Lack of flexibility and chance of iteration - Lack of normative rules/industrial standards - Lack of involvement of stakeholders in decision making
Market and Financial barriers	- Financial risk - Short-termism - Lack of awareness and understanding among market participants - Lack of marketing know-how
Behavioural and Social barriers	- Lack of consumer/customer acceptance - No stakeholder pressure - Lack of risk-taking - Enterprise culture - Inconsistent leadership - Lack of motivation - Profitability of existing business models/satisfaction

Table 3: TIS functions adapted to SBMI (Hekkert et al., 2007; Laukkanen & Patala, 2014)

Functions	Description of the original framework (Hekkert et al., 2007)	Adapted and connected to SBMI (Laukkanen & Patala, 2014)
F1 Entrepreneurial Activity	- Creating new business opportunities by making use of new knowledge, networks, and markets - Learning through experimentation under uncertainties and stakeholder feedback	- Collaboration and forming of partnerships with stakeholders around key sustainability issues as a catalyst for new innovations - Risky experimentation and pilot projects supported by encouraging regulations from policy-makers
F2 Knowledge Development	- Patents and R&D investments for tacit (know-how based on personal experience) and explicit (know-what based on codified, objective research) knowledge creation -	- Firms need an understanding of the value of sustainability-related to sustained competitive advantage, also negative financial impacts of climate change - Firms need to define new indicators for profitability linked to sustainable development - Universities and research institutes need to create and disseminate knowledge - Policy-makers need to recognize the impact of regulations on businesses
F3 Knowledge Exchange	- Sharing knowledge in networks of business R&D, governments, competitors, and market to create standards and targets based on the latest research - System actors are raising awareness, sharing capacities and resources	- Sharing knowledge in networks between businesses, governments and all relevant stakeholders - Formulating voluntary standards that are more stringent than regulations or supporting them
F4 Guidance of the Search	- Governments, Universities and Businesses are setting the direction of knowledge creation - Defining priorities of R&D investments depending on individual targets - Spreading optimism about innovation to reduce uncertainty and risks	- Prioritise long-term sustainable change with limited R&D resources - Governments steer with regulatory frameworks for emission targets and market shares of sustainable products and technologies - Aligning (inter)national sustainability regulations for a clear future innovation pathway
F5 Market Formation	- Creating a protected space in the form of niche markets for innovative products which are not yet mature - Introducing (temporary or permanent) taxes or regulations favouring the innovation	- Creating niche markets for sustainable products which are not competitive yet - Introducing (temporary or permanent) taxes, sustainability standards and regulations favouring the sustainable innovation - Public procurement preferring sustainable products

F6 Resource Mobilisation	- Financial and human capital to spur innovation especially relevant for function 2 - Resources for development and diffusion of innovation among actors of the targeted system	- Governments provide financial and human capital for R&D programs that target sustainable innovations - Creation of collaborative alliances to increase available resources - Spreading R&D programs among diverse projects to create multiple options for SBMI
F7 Counteract Resistance to Change/ Creation of Legitimacy	- Advocacy coalitions can increase legitimacy by promoting new technologies by putting them on the agenda and lobbying for resources and supportive taxes	- Create trust by spreading success stories to increase legitimacy and to encourage SBM innovators - Promotion of sustainable consumption by increasing public awareness of environmental and social issues and showing how SBM can solve those - Forming associations and lobbying for resources and supportive taxes

2.2 Literature review

The literature review explains the most critical structural elements determining the basis for innovations of Eucalyptus plantation management. The focus of this chapter lies on institutional factors, reflecting regulations and voluntary guidelines for the innovation system.

2.2.1 Governmental regulations

Government regulations and voluntary market standards such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) started promoting sustainable forest management in the 1990s (Arets & Veeneklaas, 2014). Since 2012, the Brazilian Forest Code regulates Areas of Permanent Protection (APP), Areas of Restricted Use, and Legal Reserves (RL). As a result, landowners in the Atlantic Forest need to restore the native vegetation cover of 20% of their land as RLs or compensate it with another property in the same biome. The RLs can be replanted with up to 50% exotic species, such as Eucalyptus, and allow for sustainable harvesting to compensate for regeneration costs and to make a profit (World Bank, 2017).

To comply with the Forest Code, a current deficit of 21 million hectares needs to be reforested, requiring enormous effort. The loose definition of reforestation states that land needs to be covered by tree species but does not specify how much land will be planted with exotic or native species and whether it will be monocultures or mixed forests. Highly productive exotic species are seen as a profitable opportunity for economic growth in Brazil's forestry sector, although native species would clearly outperform them in providing ecosystem services. However, there are no regulations on the requirements of ecosystem services provision for forest plantations in Brazil (World Bank, 2017). Furthermore, there is a lack of enforcement of environmental legislation, leading to a low level of compliance with the ambitious reforestation targets of the Forest Code (Bernasconi et al., 2016).

2.2.2 International regulations

Brazilian exporters and European Union (EU) importers addressed similar issues about the EU Forest Law Enforcement, Governance and Trade (FLEGT) plan, established in 2003. Weak enforcement and guidance accompanied by increased bureaucracy decrease the willingness of non-EU governments to negotiate Voluntary Partnership Agreements (VPA) with the EU to decrease illegally logged timber (Moral-Pajares et al., 2020). Brazil did not agree on a VPA yet. In this case, the EU Timber Regulation asks for due diligence to prove the legal harvesting of the timber and its products, such as pulp, that are imported into the EU. Documents about the tree species, wood origin and compliance with national regulations must be provided by the actor placing the pulp on the EU market (European Forest Institute, 2020). The EU is an important pulp customer for South America, as 40% of the exports go to the EU. Brazil's pulp market share in the EU grew from 7% in 2000 to 15% in 2015. However, besides

the efforts to decrease illegal logging, there are no specific regulations on biodiversity protection or general ecosystem preservation for Eucalyptus trade between the EU and Brazil (UNEP-WCMC, 2018).

2.2.3 International voluntary standards

In the case of missing or loose government regulations, international voluntary market standards are a much-used mechanism to promote more sustainable production (Van Oorschot et al., 2014). 63% of planted forests in Brazil are certified by independent organisations (World Bank, 2017; IBA, 2020). Although the certifications are mostly not setting higher standards than the Brazilian Forest Code, they are expected to improve enforcement of the existing legislation (Buliga & Nichiforel, 2019). Especially regarding the environmental performance of forests, standards need to improve their stringency to maintain and stimulate the provision of ecosystem services (Milder et al., 2015). Van Oorschot et al. (2016) stated that FSC certification covers ecosystem services more explicitly than PEFC, but still not all ecosystem goods and services are sufficiently addressed. Furthermore, certification of sustainable plantation management comes along with costs for the certification itself, for staff-training, and management adaptations. Plantation owners need to make these investments in the short term, which may only pay off in the long term due to market premiums for certified products (Van Oorschot et al., 2016).

Although governance initiatives are getting more ambitious and are urgently needed to promote ecosystem services in forest plantations, FSC still certifies intensively managed monocultures and does not differentiate between conventional and alternative management options. The certification of short-rotation monocultures is defended with the so-called 'spare land effect', assuming natural forests will be protected from deforestation due to the high productivity of Eucalyptus monocultures. The Forest Code obliges landowners to set aside 20% of their land as so-called Legal Reserves dedicated to natural forest regeneration. This regulation allows compensating a lack of Legal Reserves with natural forests in other areas of the same biome, making large plantations of pure monocultures possible. However, negative and positive impacts affect ecosystems locally, and ecosystem services needed in those monocultures cannot be captured from outsourced natural forest landscapes (Scherr & McNeely, 2008; Van Oorschot et al., 2016).

2.2.4 Payment for Ecosystem Services

This currently unequal distribution of costs and benefits for sustainable forest management across stakeholders in the value chain of Eucalyptus pulp could be solved by new market mechanisms in the form of Payment for Ecosystem Services (PES) (Van Oorschot et al., 2016). In 2011, FSC started to develop the "ForCES" project to measure, verify, and communicate the provision of ecosystem services in FSC certified forests. The ForCES tools resulted in an ecosystem services certification document, which allows FSC certification holders to demonstrate the impact of their forest management (for

further information on ForCES criteria see Appendix A). Thereby, it represents another step towards entering the emerging market for ecosystem services (Savilaakso & Oy, 2017). The Brazilian government also recognized the option of PES since a new National Policy for Payment for Environmental Services (PNPSA) was enforced in January 2021. The policy frames a voluntary financial transaction or a remuneration by a public or private payer to the provider of environmental services. Environmental services are understood as *"individual or collective activities that favour the maintenance, recovery or improvement of ecosystem services*". The law aims to encourage the preservation of ecosystem services (Law No. 14,119, 2021).

3 Methodology

3.1 Research Design

This study's goal was to identify and compare conventional and alternative business models of Eucalyptus plantation management. Thus, the concept of a comparative case study analysis based on business models as the level of analysis was chosen. An exploratory approach was applied since business models for the alternative approaches are not defined yet, and therefore are a subject of high uncertainty in need to explore problems and opportunities (Van Wyk, 2012). This research maps the essential components determining the conventional business models and identifies systemic changes needed to transition towards a more sustainable forest management approach. Thus, the research followed inductive reasoning, as collected data was used to outline an innovative business model for alternative Eucalyptus plantation management and the potential barriers it could face within the system it would operate in (Bryman, 2016).

This research is based on qualitative data obtained from a combination of literature research and interviews. The latter allows capturing the perspectives of relevant actors within the innovation networks of the Eucalyptus industry to gain an understanding of attitudes, experiences and predictions (Rowley, 2012). The data collection approach is explained in more detail after the description of the case selection criteria.

3.2 Case selection: Conventional vs. alternative Eucalyptus plantation management

As the first case study, the currently most applied form of Eucalyptus plantation management in the Brazilian pulp and paper industry was selected. The intensively managed short-rotation monoculture represents the status quo of the commercial business model and serves as a basis for comparisons with potential alternative systems. Alternative Eucalyptus plantation management options that could lead to business model innovation were explored through literature research with the search engine Google Scholar using the search terms (Alternative Eucalyptus plantation management OR Sustainable Eucalyptus plantation management) in combination with (Atlantic Forest OR Brazil AND Ecosystem services OR Sustainability). Articles providing information about alternative systems were further studied and served as a basis for snowballing. Alternatives chosen for this research are based on the following criteria:

1. Alternatives have a positive effect on ecosystem services provision compared to the conventional approach (Puettmann et al., 2015).
2. Alternatives include the possibility of Eucalyptus species cultivation to allow a continuous material supply to the pulp and paper industry and/or a smooth transition to new markets.

3. Alternatives are providing options for revenue by selling products/services from plantations since financial profitability is considered an essential factor for firms to consider SBMI (Bocken & Geradts, 2020).
4. Alternatives ask for different severity of the business model change, from resembling the conventional approach to a different management form to increase possibilities of potential implementation by the industry.
5. Trials for the alternatives were done in the Atlantic Forest biome to prove their ecological feasibility.

Table 4 provides a brief overview of the conventional management approach and three alternative options which serve as examples for plantation models matching the selection criteria. The alternatives are the basis for potential business model innovation and are explained in more detail in the results section.

Table 4: Selected Eucalyptus plantation management options as business model case studies

Plantation management option	**Description**
Conventional: Short-rotation Eucalyptus monoculture	Intensively managed plantations producing high wood yields providing great financial profitability under considerable negative ecological impacts.
Alternative 1: Coppice with standards Eucalyptus plantation	Duo-aged and two-layered monoculture with coppice for short-rotation pulpwood and standard trees for high-quality roundwood; Decreased short-term income; Providing improved habitat structure for fauna compared to conventional plantations;
Alternative 2: Mixed plantation of Eucalyptus with *Acacia mangium*	Plantation with two species: Eucalyptus and nitrogen-fixing *Acacia mangium;* Possibility to produce both pulp- and roundwood; Lower growth rate of Acacia compared to Eucalyptus; Decreased need for fertilisers and herbicides; Risk of invasiveness;
Alternative 3: Mixed plantation of Eucalyptus with native tree species	A mix of Eucalyptus with 23-30 native tree species; Production of pulpwood in the short-term and high-quality timber in the long-term; High positive impacts on biodiversity and other ecosystem services;

3.3 Conceptual Framework & Data collection

The following section describes the qualitative data collection embedded in the conceptual framework. Information was obtained through both literature research and semi-structured interviews to compare, extend and validate gathered data (Yin, 2009). The TIS model connected to SBMI, as suggested by Laukkanen & Patala (2014), serves as an overarching framework guiding the research.

3.3.1 Business model analysis

To answer the first research question, the conventional business model was analysed through literature research using Google Scholar with the search terms (Eucalyptus monoculture management in the Atlantic Forest), its (Ecological impacts) and (Economic analysis) and gathering grey literature from business reports of the pulp and paper industry. Simultaneously, scientific articles collected from the case study selection were reviewed for the analysis of alternative systems. The second step of the data collection was validating the desk research through semi-structured interviews guided by the business logic questions of Laasch (2018) and especially paying attention to ecosystem services provision and economic aspects of all four studied management approaches. To assess the financial profitability of the alternative options compared to the currently applied business model, the original aim was to conduct a detailed cost-benefit analysis including forest plantation implementation, maintenance, harvesting and transport costs compared to revenue from product sales. Since interview partners could not fill the gaps of missing economic data from literature or were not allowed to disclose specific economic values, the economic analysis was done descriptively, explaining expected cost factors and providing numerical values only if the information was available. As a conclusion of the analysis of potential alternatives, their diffusion and integration into business models were represented by the phase of innovation development as suggested by the TIS model (Hekkert et al., 2011).

3.3.2 Barrier analysis

As a first step, interview partners were questioned about barriers to implement alternative management options. Interview questions were guided by the barriers to SBMI by Laukkanen and Patala (2014) and were further specified to the context of sustainable forest plantation management through literature review. Therefore, the electronic scientific database Google Scholar was searched for different combinations of the terms (Barriers for sustainable business model innovation AND/OR Sustainable forest plantation management AND/OR System innovation AND/OR Transition theory). The functions of the TIS framework by Hekkert et al. (2007) supported the formulation of interview questions by pointing at all relevant aspects influencing the success of SBMI on a system level. The topics conceptualised in *Table 2* were discussed with the interview partners *(see*

Table 5*)* to examine their potential impact as barriers for alternative plantation management. Confronting interview partners with a list of potential barriers encouraged participants to overcome their potential tunnel vision of their expert position and consider a holistic sample of barriers to SBMI. Due to a lack of specific knowledge about all three alternative systems, the interview partners identified barriers representative of the grouped alternative approaches representing SBMI. Furthermore, the interview partners were asked to score the barriers they mentioned from 1 (no or slight barrier) to 4 (very strong barrier), according to how strongly they were perceived.

3.3.3 Interview partners

As *"planning for, and implementing, a systems-based SBM requires participation from all stakeholders"* (Stubbs & Cocklin, 2008), interview partners have been selected across stakeholder groups of the Eucalyptus production chain. As a first step, researchers of alternative systems and Eucalyptus plantation owners who provided land for scientific experiments were reached out to and interviewed. These two stakeholder groups made an essential contribution to data collection, as they filled the information gaps of scarce studies about the costs and benefits of alternative approaches with first-hand knowledge. The industry partners of the interviewed researchers were exclusively from the pulp and paper industry, which is why this research focuses on this sector as a potential business model innovator. Moreover, the sector proves its representativeness, as it consumed 45% of Brazil's Eucalyptus wood for pulp and paper production in 2010 (ABRAF, 2012). These initial interview partners were asked to provide contacts to other plantation owners, governmental institutions, certification organisations, and NGOs. The snowballing sample method resulted in a total number of 16 semi-structured interviews, all held as video calls and lasting between 35 and 106 minutes (*see*

Table 5). The use of an interview guide increased the reliability of the study by ensuring cross-case comparability (Bryman, 2016). The business model analysis questions of the interview guide were slightly adapted to the expertise of each stakeholder group, but all interviewees were asked the same questions for the SBMI barrier analysis. The semi-structured interview guide enabled the interviewer to spontaneously respond to unexpected and interesting topics mentioned by the interviewee, which supports the exploratory character of this research (Bryman, 2016). Examples of interview guides used for the group of scientists and pulp and paper industry are attached in Appendix B.

Table 5: Interview partners

Stakeholder group	Interview partner (in-text reference)	Date (2021)	Length (min.)
Scientists as experts for alternative plantation management options	Interviewee 1	25.05.	69
	Interviewee 2	17.05.	106
	Interviewee 3	27.05.	63
Eucalyptus plantation owners, represented by pulp and paper industry	Interviewee 4	09.06.	62
	Interviewee 5	09.06.	76
	Interviewee 6	21.06.	81
	Interviewee 7	10.06.	71
	Interviewee 8	05.07.	76
	Interviewee 9	18.06.	52
Consultant for small-scale Eucalyptus farmers*	Interviewee 10	21.07.	58
Governmental body Brazil	Interviewee 11	18.06.	60
International pulp market expert	Interviewee 12	03.06.	72
NGOs and Private Standard initiatives	Interviewee 13	01.07.	76
	Interviewee 14	06.07.	87
	Interviewee 15	02.06.	36
European Pulp Customer	Interviewee 16	05.07.	35

**Note: In this study farmers with up to 50 hectares are categorized as small-scale farmers, farmers with 50 up to 200 hectares as medium-scale farmers.*

For this research, interviews with representatives of the following five pulp and paper companies operating in Brazil were held: Suzano S.A., Klabin S.A., International Paper do Brasil, CENIBRA, and Veracel. These companies all manage their Eucalyptus plantations as short-rotation monocultures embedded in a so-called mosaic structure together with native forests. Their aim is profit maximization by selling pulp and paper from plantation wood to national and international markets. Hence, a similar business model approach applied by the addressed companies can be assumed. Furthermore, Suzano S.A., International Paper do Brasil, and CENIBRA participated in field research for at least one of the proposed alternatives to explore future business model opportunities, which is highlighted as interview partners from these businesses were able to provide first-hand data based on their own experiences. *Table 6* below gives a short overview of the interviewed companies as an introduction to exploring the currently applied business model in the results section.

Table 6: Production overview of analysed pulp & paper companies in Brazil

Company name	Production capacity (1.000 tons)	Own Eucalyptus plantation area (ha)	FSC and/or CERFLOR certified area (ha)	Plantations vs. native forest area (%)	States of Brazil with forest areas
Suzano S.A.	10,890 pulp 1,400 paper (2019)	1,300,000	87%	60% plantations 40% native forest	Espírito Santo, São Paulo, Bahia, Maranhão, Pará, Ceará, Mato Grosso do Sul
International Paper do Brasil	810 pulp 1,029 paper (2020)	72,000	100%	75% plantations 25% native forest	São Paulo, Mato Grosso do Sul
Klabin S.A	1,600 pulp 2,100 paper (2020)	271,000 (MIX of Eucalyptus and Pine)	100%	57% plantations 43% native forest	Parana, Santa Catarina, São Paulo
CENIBRA	1,223 pulp (2019)	250,000	100%	51% plantations 49% native forest	Minas Gerais
Veracel (Joint Venture of Suzano & Stora Enso)	1,090 pulp (2020)	87,556	100%	44% plantations 56% native forest	Bahia

Data only representing production located in Brazil
Sources: CENIBRA (2020); CENIBRA (2021); IBA (2021); International Paper (n.d.); Klabin (2021); Suzano (2020); Veracel (2021).

3.4 Data analysis

3.4.1 Interview coding & Data validation

After transcription of the interviews, the answers were coded in Nvivo through categorizing the content into overarching topics, such as “Business model”, “Ecological impact”, “Economic aspects” “Barriers”, and “Drivers”. The open coding approach of the exploratory research approach (grounded theory) is characterised by a data-driven and iterative process resulting in different levels of detail. Sub-levels were continuously grouped in more generalized codes through axial coding (Gibbs, 2007). As only one person coded all the interviews, the codes were exposed to subjective perception (Campbell et al., 2013). To enhance validity, the coded barriers per interview were sent to the individual interview partners to confirm the author’s interpretation. Out of 16 interview partners, 11 took part in this second round. This step was especially relevant since the author identified more barriers during the coding process than actively mentioned as such by the interview partners. The interview partners were given the possibility of validating the results by decoding wrongly interpreted barriers, changing their initial barrier scores and weighing barriers they did not score during the interview. After the interviewee iteration round, only 5 out of 152 barriers had to be decoded, which

confirmed the reliability of the coding process. As a next step, the barriers were assigned to the TIS functions based on the topic categorisation explained in *Table* 3 of the Theory chapter.

3.4.2 Barrier scoring

As explained above, interview partners were asked to give each barrier a score from 1 to 4, with the strength of the obstacle increasing with ascending number. To represent the importance of barriers, the following numerical values were analysed. First, the total number of interviewees mentioning the individual barriers shows awareness of a barrier across stakeholder groups. Second, the average score given by the interview partners to the specific barriers was calculated to present how strongly these are perceived by multiplying the number of interviewees (mentioning the individual score) with the score (given by them), summarizing the different products per score and dividing them by the total number of interviewees mentioning scores for this barrier. As an example: Barrier "Lacking implementation of Forest Code" of TIS function 4 was mentioned by interview partners 3 times, 2 of the interviewees gave a score to the barrier, one time score 4 and one time score 1. This results in an average score of 2.5, calculated as follows: (1*4+1*1)/2.

3.4.3 Function scoring

The barrier scores can also be used to determine which TIS functions face the largest blocking mechanisms that prevent SBMI of Eucalyptus plantation management. Functions with the strongest barriers are assumed to be the least fulfilled (Hekkert et al., 2011). To estimate the performance of the TIS functions, a weighted average barrier score per function was calculated to reflect both the number of interview partners who scored the barriers as well as the scores themselves. The following approach was applied: Multiplication of the individual average barrier scores per function with the individual number of interviewees giving a score to them, summarizing those per function and then dividing this value by the summarized number of interviewees giving a score to barriers per function. Example: Function 3 faces 4 barriers with average scores of: 4 (1 score given); 3 (1 score given); 2,55 (11 scores given); and 3 (2 scores given). In total 15 scores were given (1+1+11+2). The average weighted score is calculated as follows: (1x4+1x3+11x2,55+2x3)/15.

Additionally, the average number of interviewees addressing barriers per function was calculated to represent which challenging function created the most awareness across interviewees.

4 Results

4.1 Analysis of the current Business Model of the pulp and paper industry in Brazil

As described in the theory chapter, the four business logics by Laasch et al 2018 serve as the structure for the analysis of the current business model. The management approach, economic aspects and ecological impacts of short-rotation monocultures are pointed out in more detail below the business logics exploration. Deviating management approaches or business activities of individual companies are highlighted as such. The main findings are summarized in Table 7.

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Table 7: Business Model Analysis short-rotation Eucalyptus monocultures

Foundations of current Business Model	**Pulp & Paper Industry Brazil with short-rotation Eucalyptus monocultures**
Value Proposition	Products: - Pulp and Paper products from Eucalyptus wood - Carbon Credits (slowly emerging market) Product properties: - Competitive prices - High quality - Voluntary certification for responsible forest management Customers: - International & National
Value Creation	Increasing efficiency of plantation & process management: - R&D: Breeding programs for Eucalyptus species - Highly technical forestry planning - Intensified monoculture management - Mosaic system - Process adapted to homogeneous wood for high-quality pulp Resources: - Plantation area (including assets: soil, water, nutrients) - Native forests - High-quality planting material & fertilisers, herbicides, pesticides - Machines & Technologies - Knowledge and Human Resources - Financial Resources
Value Exchange	Commercial exchange context: - B2B with pulp and paper customers - B2B on voluntary carbon market Partners & Network: - Forestry Certification bodies - Carbon Certification organisations - Farmers - Universities & Start-ups
Value Capture	Revenue from products - Pulp & Paper - International & National Market - Growth and scalability
Plantation management	- Monoculture of one Eucalyptus species - Short rotation periods (6-7 years) - High fertilisers, herbicides, and pesticides input
Economic aspects	- High implementation costs - High harvesting and transportation costs - High profitability through fast-growing Eucalyptus trees
Impact on Ecosystem services	- Minimal ecosystem services provisioning - Only moderate suitability as habitat for native forest fauna - Negative impact on soil fertility and productivity - High water consumption - High wood production

4.1.1 Business Logics

4.1.1.1 Value Proposition

The industry sells pulp and paper products mainly to the international, but also to the domestic market. Pulp accounts for 66% of the exports and primarily goes to China (43%) and the United States (16%). Paper represents 18% of the planted tree sector products, mainly sold in South America (49%). The biggest pulp producer, Suzano S.A., covers a total range of 80 countries, of which their pulp customers are mainly located in Europe, Asia and Brazil, and their paper is primarily sold to South and Central America. CENIBRA has a particular focus on the Japanese market, as the owners are based there. The Brazilian pulp and paper products can be sold at an internationally competitive price, enabled by the high wood growth productivity at national Eucalyptus plantations. Processing homogeneous Eucalyptus wood at pulp mills also ensures the high quality of sold products. Besides looking for good features and an economically profitable deal, customers also value FSC and/or CERFLOR certified wood products from Brazilian Eucalyptus plantations. All interviewed companies guarantee a 100% certification rate, the only exception being Suzano S.A. with 87% of their area being FSC or CERFLOR certified. Interviewee 7 said: *"Suzano sees FSC as a strategy because [...] it is easy and faster to sell our products when you have FSC".* Certification for well-managed forests is key in the marketing strategy of all companies. Klabin claims to be recognised for its respect for nature, as it was the first company to stop harvesting natural forests in the 1970s. Interviewee 14 addressed Klabins sustainability values as follows: *"These natural forests were maintained even when sustainability as a word was not known by people, like the image or the advertisement of a company that is totally related to nature".*

Carbon credits are also frequently connected to sustainable impact. For example, as part of their sustainability strategy, Suzano S.A. announced they are *"looking into possibilities of generating carbon credits by forestry"* (Suzano S.A., 2021). Interviewee 6 confirms the company is already selling carbon from native forest restoration on the voluntary carbon market, especially to European clients in the petroleum sector but also to clients in Brazil in the mining sector. Interviewee 7 says revenue from carbon sequestration leads to a change of business models in the pulp and paper sector.

4.1.1.2 Value creation

The industry achieves high production volumes at low costs by constantly increasing the efficiency of processes with the help of technology. Eucalyptus planting companies installed breeding programs decades ago to develop trees adapted to various environmental conditions and high-quality wood that can be used for multiple purposes. *"Suzano believes that biotechnology can be a tool to keep its competitiveness and long-term sustainability of its business"* (Suzano S.A., n.d.). The homogeneity of the planting material processed in pulp mills also ensures a consistent quality of the sold products.

The forestry planning is continuously supported by remote sensing data exploring potential new plantation areas. The LIDAR (light detection and ranging) method allows scanning territory and providing information about the structure, vegetation and hydrography. It enables quick identification of areas needed to be put under Permanent Protection due to water springs or rivers. Surfaces already covered with natural forests need to be classified as Legal Reserves (interviewees 7 & 11). As *Table 6* shows, the companies have set aside 25-56% of their areas as native forests, clearly above the required 20% of Legal Reserves to comply with the Forest Code and FSC certification. These areas are not yet used for the commercial use of wood products. Interviewee 6 explained: *"for sure, it's not about environmental protection. It's about survival for the business."* In more detail, he said that when the companies were still clearing 100 % of the newly cultivated areas, insect plagues got out of control. Subsequently, the industry realised the value of natural areas for Eucalyptus production. Interviewee 14 also addressed the value of bird species living in native forests as natural biological control of pest insects. Furthermore, she addressed the importance of the mosaic structure to keep soils in good condition. Together with water and nutrients, fertile soil forms an essential asset for the productivity of forests. The availability of both is becoming an increasing problem at Eucalyptus plantations in the near future (interviewee 14). In addition to those naturally provided resources, Eucalyptus cultivation includes high input of fertilisers, herbicides and pesticides, as described in the management approach of short-rotation Eucalyptus monocultures.

4.1.1.3 Value exchange

As the industry is at the beginning of the supply chain, producing raw materials and offering pulp and paper products, their commercial product exchange takes place from business to business. This also accounts for clients of the voluntary carbon market, as far as information was available by interview partners.

The value exchange network of the industry goes beyond their product clients. Essential for their production capacity are farmers providing their land to establish plantations and grow Eucalyptus for pulp and paper companies. In Brazil, 30% of the forest plantations belong to independent farmers (interviewee 5). International Paper and Suzano S.A. resemble that ownership proportion for their Eucalyptus production. (interviewees 5 & 7). CENIBRA gets less than 20% of their wood from the market, the rest is grown on their own land (CENIBRA, 2021).

To validate responsible plantation management, the companies partner with Forest and Carbon Certification organisations to achieve FSC and/or CERFLOR certifications for their forest areas. For the Carbon Credits Certification, the organisation Verra provides standards for validation (interviewee 6). In addition, the industry maintains research partnerships with universities and collaborations with start-ups to explore new technological options to improve plantation management (interviewee 7).

4.1.1.4 Value capture

Due to the high Eucalyptus productivity in Brazil, the companies based there have very favourable cost structures compared to the global pulp and paper sector (Oliveira, 2017). Therefore, their prices are competitive, and products can be sold with profit. With an export revenue of US$ 7.5 billion in 2019, Brazil is the largest global pulp exporter, and with 19,7 million tonnes, the second biggest pulp producer behind the United States (IBA, 2020). It can be expected to stay in that top position as models claim Latin America will cover 30% of the pulp production capacity increase, of which Brazil would cover the most significant part. In the years before 2017, Brazil increased its pulp production capacity by 1 million tonnes per year (Van der Mark & Haggith, 2017). There was also a growth in paper production, reaching 10,5 million tonnes in 2019 and an increase in exports of 7.2% compared to 2018 (IBA, 2020).

4.1.2 Short-rotation Eucalyptus monoculture plantation management

Eucalyptus is non-native in Brazil, most species originate from Australia. Brazil started breeding programs to improve the phenotypic qualities of the Eucalyptus genus in 1941. Because of good traits in pulp yield, lignin, and fibre length, the pulp and paper industry mainly uses *Eucalyptus grandis* and *Eucalyptus urophylla* to produce cellulose. Hybrids as products of inter-specific crosses show additional trait gains for improved pulp production (Castro et al., 2016). Its qualities make Eucalyptus a multi-purpose species, its wood can be used to produce pulp, energy or solid wood products (Ferraz Filho et al., 2014).

Conventional Eucalyptus plantation management is understood as intensively managed monocultures primarily representing genetically identical trees. This silvicultural approach represents the majority of Eucalyptus plantations in the Atlantic Forest. The forestry model is used to achieve great wood yields and shows a high demand for resources such as water and nutrients (Bremer & Farley, 2010; Amazonas et al., 2018).

4.1.2.1 Current management approach

Operations of conventional Eucalyptus plantations are characterised by planting mono-specific stands, clear-cut harvesting after short rotation periods and high fertilisers, herbicides, and pesticides application (Virgens et al., 2016; Ferraz Filho et al., 2014).

The following approach is applicable for intensive monoculture Eucalyptus plantation management in the Atlantic Forest with the goal of pulp production: The first task is to clear the land, followed by planting Eucalyptus clones at densities of around 1111 trees/ha (3mx3m) together with an initial application of about 120 kg NPK-fertiliser/ha, which combines the nutrients nitrogen (N), phosphorus (P) and potassium (K). Over the following years, another 600kg of fertilisers are applied per ha. During

a 7-year cycle, weed control is done by an average of 9 glyphosate solution applications of 120 litres/ha. Leafcutter ant attacks also require an almost yearly use of pesticides to keep damage to a minimum. After 6-7 years, depending on the local productivity of the stand, the Eucalyptus wood can be harvested in a clear-cut with harvester machines and transported to the pulp mill (Virgens et al., 2016; interviewee 4).

4.1.2.2 Economic aspects

An economic analysis by Virgens et al. (2016) presents implementation costs as the most significant cost factor of short-rotation Eucalyptus monoculture management (based on a trial site in Bahia) with a total amount of R$ 3,840/ha, representing 58% of total costs. Interviewee 4 states that weed control, fertilisers, soil preparation and planting with initial irrigation contribute to high forest formation costs. However, interviewee 4 also mentions that the study of Virgens et al. (2016) may be outdated, as fertilisers costs have doubled within one year from 2020 to 2021. Furthermore, the study does not regard harvesting and transportation costs, which interviewee 4 addresses as most relevant, representing around 40% of the total plantation management costs. The need for machines and their fuel makes harvesting expensive, whereas for transportation the distance to the pulp mill is a crucial factor (interviewee 4).

To compensate for the costs and gain profit, as per 2021, Eucalyptus wood can be sold for an average price of R$ 70.0/m^3 in Brazil (interviewee 4). With the national average productivity of short-rotation Eucalyptus monoculture plantations of 35,7m^3/ha/year, this could lead to revenue of R$ 17493/ha/year. The high growth rates were achieved through improvements of silvicultural management and genetic material, leading to productivity three times higher than in the 1970s (Goncalves et al. 2008). However, productivity only increased by 0.2% per year from 2012-2017, slowing down profit growth following this management approach (IBA, 2017).

4.1.2.3 Ecological impacts and ecosystem services provision

In general, conventional Eucalyptus monoculture plantation management leads to a very limited capacity of ecosystem services provision (Calviño-Cancela et al., 2012; Zhou et al., 2018). Native flora diversity is replaced by non-native species and even mature Eucalyptus monocultures show only a moderate capacity to provide habitats for native forest fauna (Da Rocha et al., 2011). Other negative impacts on the ecosystem are loss of soil fertility and productivity, decreasing biodiversity through extensive use of insecticides, fertilisers and weed control and higher vulnerability for pest diseases, storms and fires. Monocultures also have a limited ability to trap nutrients in the soil and consume higher levels of water than natural forests due to their fast and high tree growth (Liu et al., 2018). The severity of the impact of water use by Eucalyptus on surrounding ecosystems depends on local climate and soil conditions (Lima et al., 2012). However, effects on ecosystem services vary with previous land

use, climatic conditions and management practices (Brockerhoff et al., 2013). Examples are allelopathic effects of Eucalyptus (Becerra et al., 2018) and reduction in soil moisture (Robinson, Harper & Smettem, 2006), which were mainly observed in drier climates but are less problematic in tropical regions with wetter climates (Brancalion et al., 2020).

Although its limited provisioning of most ecosystem services, the high productivity of pure Eucalyptus plantations under intensive silvicultural management delivers a considerable amount of wood, as described in the economic analysis above.

4.2 Alternative modes of sustainable Eucalyptus plantation management

In the following chapter, the selected alternative approaches of Eucalyptus plantation management are introduced. As besides field testing none of these modes are applied by the industry, the analysis is structured by key differences to the conventional business model. These represent the needed change of operations, private and public costs and benefits in the form of an economic and ecological analysis of the alternative plantation management impact. An overview of the analysis of alternatives is given in *Table 8.*

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Table 8: Foundations for Business Model Innovation with alternative Eucalyptus management

Foundations for Business Model Innovation	**Coppice-with-standards management in Eucalyptus grandis plantation**
Plantation management	- Duo-age monoculture with standard trees and understory coppice - Short rotation periods for coppice, longer rotation periods for standard trees - Pruning of standard trees for high-quality timber
Economic aspects	- Short-term revenue from pulpwood - Long-term revenue from high-quality Eucalyptus roundwood of higher diameters - Costs similar to conventional approach, extra costs for pruning
Impact on Ecosystem services	- Higher wildlife biodiversity through more stratified canopy - Higher flora diversity due to understory plant regeneration - Still considerable negative impact on ecosystem services due to monoculture and intensive plantation management
	Mixed plantation of Eucalyptus grandis and N2-fixing species: Acacia mangium
Plantation management	- Eucalyptus intercropped with Acacia trees - Pruning of Acacia trees
Economic aspects	- Short-term revenue from Eucalyptus pulpwood and Acacia - Potential for long-term roundwood production with Acacia - Decreased expenses for fertiliser - Reduction of weeding costs due to sooner canopy closure - Potential for increased wood growth productivity due to nitrogen-fixing of Acacia trees - Higher harvesting costs
Impact on Ecosystem services	- Improved soil nutrients cycle - Higher fungus and bacteria diversity in soil - Improved habitat for native fauna due to stratified canopy - Invasive character of Acacia
	Mixed plantation of Eucalyptus grandis and highly diverse native tree species
Plantation management	- Eucalyptus intercropped with ~30 native tree species - Model designed for restoration purposes but also feasible for permanent commercial wood production - Thinning of poorly formed native trees
Economic aspects	- Short-term revenue from Eucalyptus pulpwood - Long-term revenue from high-quality native species timber - Higher productivity of individual Eucalyptus trees compared to monoculture - Higher harvesting costs

Impact on Ecosystem services	- Increased biodiversity of native fauna and flora - Improved habitat for fauna due to more complex stand structure - Improved nutrient cycle in the soil - Lower water consumption - Decreased wood production

Note: Mainly differences to conventional management addressed

4.2.1 Coppice-with-standards management in Eucalyptus grandis plantation

The coppice-with-standards (CWS) silvicultural management system represents a duo age monoculture. It consists of two layers, a low density of standard trees forming the overstory and providing seeds to the understory treated as coppice (Ferraz Filho et al., 2014). The aim of the CWS system is to sell wood for multiple purposes, such as for energy and pulp (understory) and solid wood products (overstory) (Soares et al., 2003). Due to their excellent sprouting capacity and possibility for large dimensions, Eucalyptus species such as *E. grandis* are well suited for this approach (Higa & Sturion, 1991; Sims et al., 1999). In addition, the product diversification potential makes this system especially interesting for small- and medium-scale landowners to spread the risk of financial loss among multiple income sources (Reynders, 1984; Soares et al., 2003).

4.2.1.1 Management approach

After planting, the first silviculture measure is the selection of standard trees based on their dominance, stem form, absence of defects, and homogeneous distribution in the stand. The number of standard trees per ha depends on the desired target diameter and coppice yield and range between 25 to 200 trees/ha. Few standard trees (25-50) lead to high diameters, greater coppice yields and also simplify machine harvesting of the coppice (Ferraz Filho et al., 2014). In addition, pruning up to 50% of the standard tree crowns at the time of canopy closure increases wood quality (Forrester et al., 2010). After 5-7 years, the Eucalyptus coppice reaches commercial dimensions and can be cut for the first time. The number of coppice cuts before harvesting the standard trees is determined by their target diameter (Ferraz Filho et al., 2014). Nutto et al. (2006) reported *E. grandis* diameters of 54.5cm in a stand with 115 standard trees/ha after 15 years, based on experiments in the South-East of Brazil. De Rezende et al. (2005) recommended two coppice cycles before standard tree harvesting for Eucalyptus due to availability of highly productive genetic material. Besides genetic and environmental factors, the following operational measures determine a successful CWS management: sloping cut of coppice at right stump height (12 cm) to prevent water settling (Matthews, 1991), fertiliser application after coppice cut, ant, termite and weed control, and sprout thinning to reduce competition (Stape 1997; Ferraz Filho et al., 2014).

4.2.1.2 Economic aspects

Research on economic aspects of CWS for Eucalyptus in Brazil is very limited, only one study from Inoue and Stöhr (1991) could be found. The authors reported that *E. grandis,* under CWS management, is more profitable than simple coppice, if standard trees can be sold for 1.4 times higher than the price of the coppice (25 standard trees/ha). If prices are three times as high for the Eucalyptus roundwood, the most profitable densities would be 200 standard trees/ha. The importance of higher prices being paid for large diameter wood was also stressed by interviewee 1. He is convinced that a CWS system can be more profitable if the challenge of finding a buyer for solid wood and transport logistics is overcome. This is also confirmed by literature, which states that large-diameter timber sold at higher prices can also be transported economically over longer distances (Ferraz Filho et al., 2014). About operational costs of a CWS Eucalyptus plantation, interviewee 1 stated that the implementation, maintenance and logging expenses are expected to be very similar compared to short-rotation Eucalyptus monocultures. Still, the extra workforce for selecting standard trees and pruning their crowns have to be taken into account. These steps also require training to gain knowledge and sensitivity for the CWS system (interviewee 1).

4.2.1.3 Ecological impacts and ecosystem services provision

In general, CWS forests show a higher diversity in wildlife compared to coppice without standard trees, as these form an additional layer and therefore provide a more complex structure serving as habitat for insects and bird species (Lassauce et al., 2012; Lindenmayer & Hobbs, 2004; Fuller & Warren, 1993). The standard trees also serve as dead wood sources, supporting saproxylic insect diversity (Lassauce et al., 2012). Flora diversity may also be enhanced due to understory plant regeneration in CWS stands (Ferraz Filho et al., 2014). Interviewee 1 also mentions roundwood production as a relevant ecosystem service product. Growing Eucalyptus sold on the Brazilian timber market could substitute wood from illegally harvested native trees and therefore protect primary forests.

However, interviewee 1 also addressed that besides the positive aspects compared to a short-rotation Eucalyptus plantation managed under CWS, it still represents intensively managed monocultures, and *“any monoculture that is that extensive negatively impacts ecosystem services”.*

4.2.2 Mixed plantation of Eucalyptus grandis and N2-fixing species: Acacia mangium

Acacia mangium is a tropical tree native to South-East Asia and Australia, where it is frequently used in plantations. Like Eucalyptus, it is highly productive and adapted to very poor soils. Its wood qualities (hard white wood and high calorific value) allow usage for a variety of purposes such as furniture, charcoal and pulp (Hegde et al., 2013). As *A. mangium* is a nitrogen (N) fixing species, it can support Eucalyptus productivity through enhancing nitrogen availability in the soil in mixed plantations

(Forrester et al., 2006). The similarities and facilitating attributes make *A. mangium* an interesting option to be applied in mixed plantations together with Eucalyptus species (Bouillet et al., 2013).

4.2.2.1 Management approach

In general, conventional plantation management, such as in Eucalyptus monocultures, can be carried out in mixed plantations of *E. grandis* and *A. mangium.* The Acacia seedlings can be planted between Eucalyptus plants in the same planting rows to not disturb mechanized silviculture management (Laclau et al., 2008). However, Santos et al. (2016) stated that some management options still have to be tested to facilitate harvesting. They specifically address pruning Acacia trees to get single-stem trees or planting the individual species in double rows instead of plant alternation within rows. The latter could also decrease competitive pressure and hence increase the productivity of Acacia.

When comparing the results of two studies that experimented with mixed species plantation of Acacia and Eucalyptus in the Atlantic Forest region of Brazil, it becomes evident that the site selection and climatic conditions influence the above-ground biomass accumulation of the stands greatly (Bouillet et al., 2013; Santos et al., 2016). *A. mangium* was suppressed by Eucalyptus grandis in states with milder climates of 19-23°C average annual temperature (Minas Gerais & São Paulo), resulting in an equivalent or lower stemwood biomass production compared to Eucalyptus monocultures in the same regions (Laclau et al., 2008; Bouillet et al., 2013). Santos et al. (2016) observed a higher production of aboveground biomass in their trial in the state of Rio de Janeiro compared to Eucalyptus monocultures. This is due to the higher temperatures and humidity, as well as the lack of nutrients in the soil, which favours the nitrogen supply for Eucalyptus trees by Acacia. Hence, the selection of the location plays an essential role for successful wood growth and should be considered carefully.

4.2.2.2 Economic aspects

As mentioned above, studies show different productivity outcomes of Acacia and Eucalyptus mixed plantations compared to Eucalyptus monocultures, so an increased economic benefit from stemwood revenue cannot be generalized for such mixed species plantations (Bouillet et al., 2013; Santos et al., 2016). However, a clear advantage of mixed species is a decreased need for N fertiliser (Laclau et al., 2008; Bouillet et al., 2013). Interviewee 2 also estimated an increased availability of inorganic soil phosphorus through higher production of phosphate enzymes in the mixed plantation system, which is confirmed by literature (Forrester et al., 2005; Boyden et al., 2005; Hinsinger et al., 2011). Better availability of nitrogen and phosphorus would decrease the fertiliser expenses compared to Eucalyptus monocultures, which is especially relevant as fertilisers prices doubled from 2020 to 2021 in Brazil (interviewee 4).

Behling et al. (2011) report a reduction in weeding costs by the faster canopy closure through Acacia in mixed plantations. Interviewee 4 also highlights *this "very effective cultural weed control"*, as *"after one or two years we will spend less on herbicides in mixed plantations which we used to apply each year during the whole cycle in monocultures*".

However, interviewee 4 stated that harvesting costs might be higher in mixed plantations, as varying trunk shapes between species might complicate machine harvesting.

4.2.2.3 Ecological impacts and ecosystem services provision

For interviewee 5, the enrichment of the soil with organic matter and nutrients without losing wood productivity is an essential aspect of mixed Eucalyptus and Acacia plantations in Brazil, where most forest plantations are located on poor, sandy soils. Furthermore, higher litter fall of Eucalyptus mixed with Acacia show potential for increased soil carbon sequestration compared to monocultures (Bouillet et al., 2013). Besides that, interviewee 2 claims that the biodiversity of fungus and bacteria is richer in soils of such mixed plantations than Eucalyptus monocultures. Santos et al. (2016) also pointed out that the canopy is more stratified, as Eucalyptus outcompetes Acacia in height growth. A more complex structure could serve as better habitat for native fauna.

Important to mention is that Acacia is a non-native and invasive species in Brazil. Interviewee 6 points out that this trait must especially be considered in the North of Brazil but is less of a problem in states South of São Paulo, where the climatic conditions are cooler and less humid and therefore limit the invasiveness of the species. Another negative issue could be soil acidification because nitrogen-fixing species produce Ammonium. Therefore, monitoring the Ph levels is essential to find the right ratio of acacia and Eucalyptus trees for a mixed plantation (interviewee 2).

4.2.3 Mixed plantation of Eucalyptus grandis and highly diverse native tree species

Mixed species forestry provides an option to combine internationally demanded forest restoration in the tropics of Brazil with the delivery of multiple-purpose wood products (Chazdon et al., 2017; FAO, 2016). Such a system can be attractive for the pulp industry and local farmers by planting fast-growing Eucalyptus for short-term income together with a variety of native species that provide a conservation value as well as long-term income through high-value timber (Brancalion et al., 2012).

4.2.3.1 Management approach

For a mixed species plantation of Eucalyptus and native trees, the silvicultural management approach by Amazonas et al. (2018) carried out at three trial sites in the East of Brazil could be followed. The research project aimed to provide a model that allows offsetting implementation costs by harvesting the Eucalyptus from the mixed plantation following the long-term goal of forest restoration. However, the authors state that this mixed forest plantation model could also be used for permanent production

systems. Amazonas et al. (2018) simultaneously planted alternating rows of Eucalyptus and 23-30 native tree species. Fertilisers, herbicides, and insecticides were applied as typical for other short-rotation Eucalyptus plantations in the region. Other researchers also suggest thinning of poorly formed or suppressed trees in tropical mixed species plantations. It would generate income and support the regeneration of native species that suffered from competition (Erskine et al., 2005; Nguyen et al., 2014). In the experiments of Amazonas et al. (2018), the clonal Eucalyptus grew faster than native trees, leading to a slower diameter growth of native species compared to pure native stands. Although native species experienced intense competition for light, they showed no mortality. Planting designs other than alternating rows (e.g., double/triple rows of Eucalyptus followed by double/triple rows of native tree species) could be tested to decrease competition between the fast-growing Eucalyptus and native tree species. Another supportive option would be to plant slower-growing species one year earlier (Kelty & Cameron, 1995; Nguyen et al., 2014).

4.2.3.2 Economic aspects

In mixed plantations with native tree species, 50% of Eucalyptus plants produced 75% of the wood harvested in monocultures, achieved by larger diameters of Eucalyptus individuals compared to those monoculture plantations. This might be the result of decreased competition between and within species. Eucalyptus trees grew faster, hence benefitted from greater light access and were able to take up more resources than native tree species. Moreover, the nitrogen-fixing native trees supported Eucalyptus growth (Amazonas et al., 2018). The high productivity and fast growth of Eucalyptus in this system allow rapid economic return within a relatively short rotation time of 4-5 years. In experiments, the wood reached diameters of 15-25cm on breast height and could be sold for 28 US$ per m^3. Nguyen et al. (2014) stressed that silvicultural design needs to be adaptive to the market for the promotion and economic success of mixed species plantations. Eucalyptus wood shows this flexibility through its versatile usage options that allow harvesting at different dimensions and for different purposes (Amazonas et al., 2018).

As logging of Eucalyptus with harvesters only caused damages in 11% of the native trees, of which there was no mortality observed seven months after harvesting, the production and revenue of high-quality timber from native tree species can be included in the economic model for the medium-long term of such a mixed species plantation (interviewee 3; Brancalion et al., 2020).

Due to similar silvicultural operation measures applied compared to Eucalyptus monocultures, costs are also not expected to deviate significantly. Weed control costs could be expected to be lower due to quicker canopy closure in mixed plantations (Brancalion et al., 2020), but harvesting costs are expected to be greater due to the complexity of the stand structure in mixed species plantations (interviewee 3).

4.2.3.3 Ecological impacts and ecosystem services provision

The increased biodiversity of flora compared to monocultures is very clear in the mixed plantations of Eucalyptus and native wood species. Amazonas et al. (2018) included threatened, highly valuable timber species and species attractive to fauna in their trial. The tree diversity leads to a heterogeneous canopy as an attractive habitat for many bat and bird species. The richness of regenerating native tree species was also not negatively impacted by Eucalyptus competition or harvesting (Brancalion et al., 2020). Pereira et al. (2019) positively address the increase of nitrogen and carbon in the soil of mixed plantations with Eucalyptus and nitrogen-fixing native tree species. An improved nutrient cycle was reported by interviewee 3, who also reported a lower water consumption compared to monoculture plantations. The mixed species plantations by Amazonas et al. (2018) also show no allelopathic effects and soil moisture reduction, as previously reported about Eucalyptus plantations (Becerra et al., 2018; Robinson, Harper & Smettem, 2006). Important to note that studies reporting water stress due to Eucalyptus plantations were conducted in areas of drier climates compared to trials of Amazonas et al. (2018) (Brancalion et al., 2020).

A downside of the mixed species system compared to monocultures in terms of ecosystem services is the lower timber output. This results from planting a lower density of Eucalyptus compared to monocultures and native trees did not grow as fast. There was no productivity decrease of Eucalyptus in trials, as the individual Eucalyptus trees even showed a better productivity when planted in combination with native tree species compared to pure Eucalyptus stands (Amazonas et al., 2018).

4.3 Phase of Development for Sustainable Business Model Innovation

All industry interview partners involved in field tests of the alternative management approaches confirmed that there was no commercial application after the experiments. The field tests and experiments can be considered as not successful, as they did not reach the goal of being profitable Eucalyptus management options for the plantation owners, hence there is no working prototype. These factors leave the Sustainable Business Model Innovation in the pre-development phase. From this analysis step onwards, the three studied alternatives are grouped together to represent potential SBMI during this research.

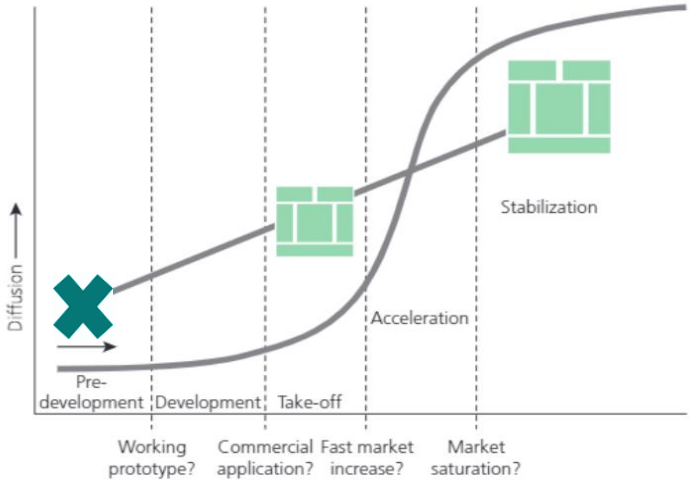


Figure 3: Phase of development for Sustainable Business Model Innovation regarding alternative plantation management (reprinted from Hekkert et al., 2011, p.9)

4.4 Barrier Analysis

The following chapter shows which barriers hinder sustainable business model innovation for Eucalyptus plantation management. The barriers were analysed according to the seven TIS functions to explore the most significant blocking mechanisms.

4.4.1 Phase of development

Hekkert et al. (2011) especially highlight the contribution of the second function 'Knowledge Development' for innovations in the pre-development phase, as prototypes of alternative management approaches are still subject of experimentation. The second function is expected to be mainly influenced by function 3 'Knowledge Exchange', function 4 'Guidance of the Search' and function 6 'Resource Mobilisation' to hamper or spur innovation (Hekkert et al., 2011). Since this research applied an exploratory approach, barriers for all seven TIS functions were analysed to identify blocking mechanisms that need to be overcome for a transition to a sustainable business model applying the suggested alternative Eucalyptus plantation management approaches.

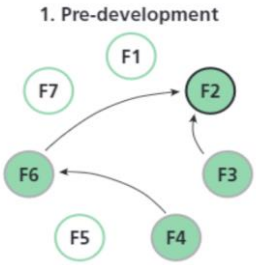
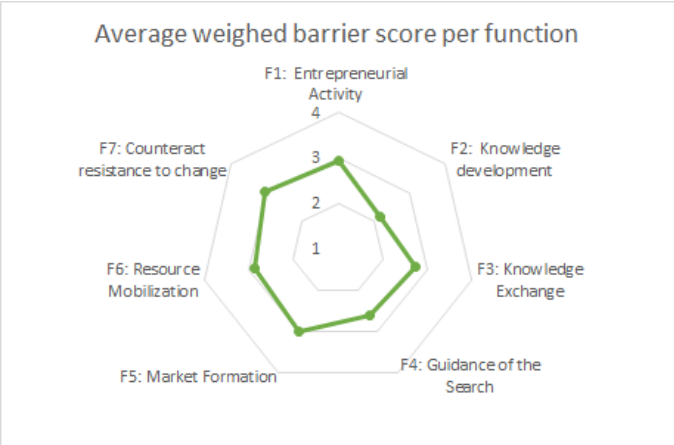


Figure 4: Possible functional interactions during the pre-development phase of an innovation system (reprinted from Hekkert et al., 2011, p.12)

4.4.2 Function performance through barrier scoring

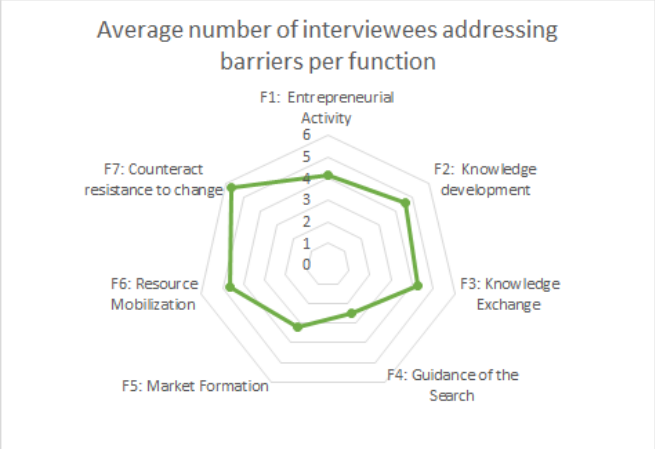
The average weighted barrier scores are represented per function in *Figure* 5. All functions show average scores above 2, which means that overall barriers are considered at least medium strong. Function 2 'Knowledge Development' shows the lowest average barrier score, assuming this function is the best fulfilled. Function 1 'Entrepreneurial Activity', function 5 'Market Formation', and function 7 'Counteract Resistance to Change/Legitimacy' face the biggest blocking mechanisms to system innovation.



Function	Mean weighed score
F1	2,96
F2	2,16
F3	2,73
F4	2,60
F5	3,00
F6	2,86
F7	3,05

Figure 5: Average weighed barrier score per function

Figure 6 below presents the average number of interview partners that addressed barriers related to the individual TIS functions. It shows a clear consistency of importance of function 7, representing the highest values in both analyses, whereas the highly scored barriers of functions 1 and 5 were mentioned by less interview partners than challenges for other functions.



Function	No. of IV
F1	4,14
F2	4,57
F3	4,25
F4	2,50
F5	3,17
F6	4,64
F7	5,71

Figure 6: Average number of interviewees addressing barriers per function

4.4.3 Barrier analysis per function

A detailed barrier analysis per function below presents their average scores and the number of interviewees referring to them. The blocking mechanisms are individually described and underlined with quotes from the interviews.

4.4.3.1 F1 – Entrepreneurial Experimentation and Production

The overarching strong barrier to function 1 'Entrepreneurial Experimentation and Production' is lacking financial profitability, which makes exploration of the new approaches risky and leads to a focus on the current monoculture management.

Table 9: Barriers F1

Barrier name	Number of interviewees mentioned	Average score [1-4]
Lacking productivity and profitability of alternative systems	10 (63%)	3.11
Focus on short-term profitability with monocultures	5 (31%)	3,20
Focus of pulp industry on small-scale farmers to implement alternatives	5 (31%)	3
Failed projects in the past	5 (31%)	2.25
Risk aversion of managers in pulp industry due to high pressure	2 (13%)	4
Eucalyptus monocultures are risk-free income for small farmers	1 (6%)	1
Medium-scale farmers (200ha) want simple management	1 (6%)	-

To explore the potential of the proposed alternative management options introduced in this thesis, many industry interviewees have participated in field research in collaboration with universities or even attempted to carry out larger projects. The trials have all been completed, and none of the alternatives is currently being implemented on a larger scale by the companies studied. Interviewee 7 gave an example:

"Fibria 20 years ago was trying to do that [mixed species plantation] in South of Bahia. They were trying to build a very big sawmill and then it didn't work out because they had a problem with logistics. They have problems selling the product and the company focus wasn't wood, it was pulp and paper. So yeah, in a big crash in 2009 and 2010, they decided, no, let's stop doing that because this is not our core business, our core business is pulp and paper and then they gave up".

The reasons for failed projects in the past and non-continuation are diverse, but the main barrier is lack of financial profitability, representing the most frequently named barrier for function 1 of the TIS. If the new business model is not as profitable as the current one, entrepreneurs lose motivation to

innovate by trying alternative Eucalyptus management concepts. Interviewee 4 framed it as follows: *"I think the key point is the economical point. The other points are also important, but first of all, we have to show and prove that this other way to plant a forest can be competitive with Eucalyptus plantations".* Then companies would continue to invest in exploring alternatives on a larger scale.

The lack of profitability can be explained by the lower productivity of alternative systems compared to Eucalyptus monocultures. A reason given for that is lower growth rates of Acacia in the optimal zones for Eucalyptus, such as expressed by interviewee 4: *"We have two different kinds of climates. In one region, it's more hot and the other more cold. In the cold areas the growth of Acacia is not satisfactory. In hot areas they grow well, but in the cold area it is a little bit more complicated for us".* He also pointed out that the pulp yield of Acacia wood is lower, as Eucalyptus has a 10-20 % higher wood density. For the CWS management or a mix with native tree species, longer payback periods lead to financial loss in the short-term. This challenge is especially relevant for small-scale farmers, as "*it would occupy a part of their lands that they can't set aside for the time the native trees need"* (interviewee 10). However, also for the big players of the pulp and paper industry, *"it's all about maximising the short-term profit"* (interviewee 3). This mindset also puts great pressure on managers to achieve high yields, so they do not take the risk of experimenting with new approaches. This barrier was given the highest average score in the first TIS function and can be underlined by the following quote: *"They can fire you within one day if you don't reach the goals. It is not a good situation to take risks*" (interviewee 2).

Although the industry shows reluctance to implement the alternatives, it considers them a suitable option for smallholder farmers, such as emphasized by interviewee 6: *"Suzano is interested in this management, but not for their own areas".* Especially in southern Brazil, where the availability of new plantation land is limited, the industry relies on sourcing from smallholders, who do not always want to plant only Eucalyptus in their area. Instead of currently planted crops, they could implement mixed Eucalyptus plantations to have a diversified income (interviewee 6). Contrary to this statement, and despite being mentioned only once and ranked as the lowest barrier, small-scale farmers value Eucalyptus monocultures as risk-free income and medium-scale farmers (~200ha) prefer monocultures that require low effort, as they consider their plantations as savings and pursue other jobs in their daily lives (interviewees 12 & 10).

4.4.3.2 F2 – Knowledge Development

The barriers to fulfil the 'Knowledge Development' function show a lack of motivation to change the business as usual due to missing research about potential alternatives, their biodiversity impacts and how to monitor these.

Table 10: Barriers F2

Barrier name	Number of interviewees mentioned	Average score [1-4]
Missing research about alternative models, focus exclusively on Eucalyptus species	9 (56%)	3
Missing information about biodiversity benefits in pulp and paper industry	7 (44%)	2.57
Acacia is invasive in parts of Brazil	6 (38%)	3
Pulp and paper industry sees no need to change	4 (25%)	2.66
Ecosystem services are hard to monitor	4 (25%)	1.5
Impact and vulnerability of monocultures need to be evaluated	1 (6%)	4
Other negative ecological impacts Acacia (besides invasiveness)	1 (6%)	1

The barrier mentioned by most interview partners concerning the function 'Knowledge Development' was missing research about alternative Eucalyptus plantation management options. The average score of 3 out of 4 also shows that the lack of information on ecological impact, financial viability and operational management of the alternatives was perceived as a strong barrier. Interviewee 13 addressed the intensive research focus on the improvement of Eucalyptus monocultures in Brazil, whereas other species were neglected: *"It's been 70, 80 years of research of all the best universities in Brazil to focus on Eucalyptus. We don't have enough research on native options […] and that is why we are only looking for projects with Eucalyptus and not for other projects"*. Interviewee 15 added to that, explaining that especially technical and forestry management information is still very scarce for options that integrate native species in Eucalyptus plantations. Concerning the CWS approach, interviewee 1 explained: *"it is not at all largely applied in Brazil because if you try to find it, you'll see there is very, very little information on Brazilian trials".* Interviewee 3 criticised one-sided research demonstrated by the example of Acacia and a lack of attention to the invasiveness of the species: *"This is an example on the ecological side how focussing on one problem, like adding nitrogen to the system, may create a much higher environmental problem if you don't have a broader vision on the surrounding and evaluate how the species will behave on that ecosystem in particular".* Interviewee 3 called it a typical example of a biological invasion of a species brought to a region to solve one specific problem [fertilization of Eucalyptus] but creates many other issues. The risk of acacia spreading in legal reserves should be highlighted, as the Forest Code would require landowners to remove the species from those reserves (interviewee 10). Due to climatic conditions, Acacia disseminates fast in the north of Brazil, while it is not much of a problem in the southern part of the Atlantic Forest (interviewee 6). Other risks associated with planting Acacia are soil acidification or root-rot disease, but these aspects were only

mentioned by one interview partner and given low relevance as it can be compensated for by appropriate forest management (interviewee 2). Interviewee 3 concluded as follows: *"So I think that we have some individualised research on mixed plantations, but it's not yet framed to present a full new package to the forestry sector".*

For firms to implement the alternative approaches, they need to understand their value for sustained competitive advantage. Seven interview partners addressed missing information about the benefit of increased biodiversity for the pulp and paper industry as a medium to strong barrier. For example, interviewee 7 stated: *"we know that the native forest provides us with ecosystem services. But today we cannot measure that. We know but we don't measure. So I don't understand the impact of ecosystem services in my business".* This statement also introduces the barrier of how to monitor and hence prove additionality of ecosystem services when implementing alternative management approaches instead of Eucalyptus monocultures. This information would be particularly important if missing revenues from alternative systems need to be compensated by payment for ecosystem services schemes (interviewee 3).

The missing proof of benefits leads the pulp and paper industry to see no need of changing their business model. According to them, the mosaic structure of their plantations and native forests sufficiently fulfils ecosystem services. Interviewee 12 criticised that *"they might as well in their speeches say the amount of forest they are preserving […] but in one area you have kind of a dead space because you just have one culture and it's distant from the ones with more diversity."* Another interviewee from the industry pointed out: *"everybody, our company, like our CEO, they think Eucalyptus plantation is the best thing in the world. You are positive, climate positive because you plant trees, tree is life"* (interviewee 7). This quote confirms the importance of raising awareness about the impact of Eucalyptus monocultures. Only mentioned once but given the highest score in this function is the need for vulnerability evaluation of the current plantation system. Interviewee 4 stated their priority is to deal with the impacts of increased soil densities through heavy machines and water stress due to climate change before they can address aspects of diversity in their plantations.

4.4.3.3 F3 – Knowledge Exchange

The overarching barrier in the third TIS function 'Knowledge Exchange' is a need for dialogue and awareness creation about ecological impacts and the general potential of alternative plantation management approaches including all stakeholders that are affected throughout the cellulose production chain.

Table 11: Barriers F3

Barrier name	Number of interviewees mentioned	Average score [1-4]
Missing trust in alternatives and role models for small-holders	11 (69%)	2.54
Partnerships and dialogue across whole supply chain needed	4 (25%)	3
ForCES (by FSC) tool hard to use for other areas than reserves	1 (6%)	4
Lacking stakeholder involvement for FSC regulations	1 (6%)	3

By far the most addressed barrier in the function 'Knowledge Exchange' is the missing trust in alternative systems by small-holders, as mentioned by 11 interviewees. The origin of doubt is frequently lacking education or a limited information flow, as interviewee 12 pointed out: *"Quite many of them don't have the same level of education, and the corresponding environmental awareness and also the benefits of preserving".* Interviewee 11 addressed that research about alternative systems is often reporting general sustainability advantages for the environment and hence the society, but does not address the direct profit for the plantation owners, who might think: *"you are coming from the city to tell me that it will be good for you, but what about myself"*. Therefore, missing role models that reassure small-holders are needed, as the following quote underlines: *"You have to try to find the leaders and the ones that will be able to show the idea if it works"* (interviewee 11). Interviewee 13 also highlights the importance of rural farmer associations in the transition process as follows: *"If we don't include the stakeholders, the part of the supply chain that will implement [rural farmers], we are failing".*

Connecting stakeholders across the whole cellulose production process to assist each other with know-how or sharing responsibilities would require partnerships. Interviewee 7 even stated that: *"The only way I see Suzano working with alternative eucalypt plantation management systems is doing partnerships",* and provided an example: *"So a sawmill partner is going to use our land to do this kind of alternative Eucalyptus plantation in our legal reserve, for example. […] And then if things start to get better you're going to our plantation".*

Two barriers that are connected to knowledge exchange and participation around the FSC certification were only mentioned once but scored as a very strong barrier (ForCES tool) or strong barrier (stakeholder involvement). Industry interviewee 9 said they were using the ForCES tool in a natural reserve to certify biodiversity conservation as an ecosystem service. However, the application of the tool is very complex and needs time to be integrated, as *"even the people that do the certification, they were not really familiar with that".* Furthermore, stakeholder involvement in the creation and

discussion of FSC regulations is lagging, as few invited groups have shown interest in participating (interviewee 15).

4.4.3.4 F4 – Guidance of the Search

Barriers identified in the 'Guidance of the Search' context are mainly uncoordinated and lacking sustainability regulations and governmental support that lead to uncertainties about new approaches.

Table 12: Barriers F4

Barrier name	Number of interviewees mentioned	Average score [1-4]
Brazilian governance is split up in 26 largely autonomous states	4 (25%)	2.5
Lacking implementation of Forest Code	3 (19%)	2.5
Insecurity about Forest Code enforcement	3 (19%)	2.5
Government approving monocultures	2 (13%)	2.5
Missing public policy interventions for long-term success of alternatives	2 (13%)	3
Fear of harvesting ban if plantations are too diverse	1 (6%)	-

Concerning regulatory frameworks, the Brazilian Forest Code lacks in implementation. Interviewee 11 stated: "I think we have a very good law in Brazil. We just have a lack of implementation. So we have this law for 10 years and we are still struggling to implement it". Stricter enforcement could spur innovation of alternative approaches, such as mixed plantations with native species, that can be tested in Legal Reserves before being applied in plantation areas (interviewee 3). Closely connected to that is the barrier of separated regulations among the federal states of Brazil, which each need to set up their own indicator set to track the Forest Code implementation, as expressed by the following quote: "Now we have about 10 states, almost half of the states already have indicators for monitoring the process. But we still have more than 10 states that still need to develop and launch indicators for monitoring this process. So still, we have a long way to walk" (interviewee 11). The lack of implementation can also be explained by the doubt of landowners as to whether the Forest Code will really be enforced, as "people wait some time to see if it will not change. So we need to be confident that this will really be enforced" (interviewee 11). Another barrier connected to legislation is lacking guidance of the search by the Brazilian government, as they are approving monocultures instead of pushing the industry to change their approach. Interviewee 1 stressed that: "I think for the large-scale companies, you either have to, you know, it has to be mandatory or they're not going to do it". Interviewee 11 mentioned that landowners are afraid of not being allowed to harvest their plantations anymore if

they would allow their understory to grow. Such insecurities need to be ruled out by clear regulations that support the applicability of mixed species plantations. Policy interventions to ensure long-term success of alternative plantation management are missing in general, as framed by the following quote: "We have farmers that are models, we have pilot implementations everywhere, but they're not organised. So we need public policy that connects that. And I think that's something that the state can do" (interviewee 13).

4.4.3.5 F5 – Market Formation

Barriers to 'Market Formation' are in general perceived to be relatively strong, also representing very high average scores. The challenges address an unequal level playing field for alternative products and range from the lack of market structure and strong competition to the lack of support for market development through standards or regulations.

Table 13: Barriers F5

Barrier name	Number of interviewees mentioned	Average score [1-4]
Missing market structure for alternative wood products	6 (38%)	3
FSC certification does not differentiate between management approaches	5 (31%)	2.75
High international competition to produce cheap pulp	4 (25%)	3.25
Missing market structure for ecosystem services	2 (13%)	3.5
Illegal harvesting increases market competition	1 (6%)	3
Lacking EU regulations for sustainability of imports	1 (6%)	2

When addressing the missing market structure for alternative products, interview partners mentioned it would be hard to find an offtaker for other wood than Eucalyptus. There is a lot of insecurity around alternative species and regularity of their demand, as underlined by interviewee 13: *"We need the offtaker. We need the one that is going to sign a contract and says, look, I'm going to buy your production, whatever it takes"* and interviewee 15: *"If Eucalyptus, which already has a consolidated market in Brazil, already brings this "price" problem, imagine planting a species that doesn't even have a market".* Two interview partners also addressed the missing market structure for ecosystem services, which represents the strongest barrier within this function. The main points of critique are that ecosystem services other than carbon are neglected and that the source of carbon sequestration itself is not seen critically enough, as explained by interviewee 7: *"We need to think about carbon not as just*

carbon. We need to think about green carbon that comes from a land that also gives us water, good water, biodiversity and stuff like that."

Intense competition in the production of cheap pulp due to pressure from international markets (China, Indonesia, Africa) or illegal logging in Brazil also promotes the persistence of highly productive Eucalyptus monocultures. The following quotes represent these strong barriers of competition: *"The forest sector, we are competing in the world against people that are producing pulp with native species, are producing pulp devastating areas, so most of the time their costs are lower than here in Brazil''* (interviewee 6). Interviewee 1 stated, that: *"It's not that you can really compete with this illegal forestry. There's no way you're going to get that price, you're not going to be able to fight this".*

Lacking support from FSC in creating a market for products from alternative plantation management was scored as a medium to strong barrier. Interviewee 1 made the following suggestion: *"FSC or any other kind of certification scheme could put a premium on these different types of management to show that you have a different kind of forest and it's not just monoculture but there is other services, and I don't think I've seen a certification that has this kind of grade".* One interview partner also identified missing EU regulations or goals that target ecosystem services provisioning when sourcing pulp and paper products from international markets like Brazil (interviewee 12).

4.4.3.6 F6 – Resource Mobilisation

Lacking 'Resource Mobilisation' is represented by the broad range of resources needed for pulp and paper business models to innovate. The challenges reach from operational and technical infrastructure capacities, land resources, education, financial means to certification support.

Table 14: Barriers F6

Barrier name	Number of interviewees mentioned	Average score [1-4]
Harvesting and transport complexity of alternatives	7 (44%)	3.57
Needed general change of operations & management for alternatives	7 (44%)	2.83
Needed training, technical assistance, seedlings, extra workforce for small-scale farmers	7 (44%)	2.33
Land sparing instead of land sharing approach by industry	5 (31%)	2.4
Missing subsidies for pulp and paper industry	5 (31%)	2
No material uniformity for pulp mills with different species	4 (25%)	3.5
Missing subsidies for small-scale farmers	4 (25%)	3
Needed time management skills for continuous production with alternative systems	4 (25%)	3
Focus of governmental funds on powerful agriculture sector	3 (19%)	3
Certification hurdles for small-scale farmers	3 (19%)	3
Needed help to unlock existing funds	2 (13%)	3

Most addressed and highest ranked are the difficult harvesting conditions in mixed or uneven-aged plantations and the transport complexity due to the organisation of different offtakers for multiple wood products. Harvesting needs to be done more carefully, so native trees in mixed plantations are not damaged, as these should be sold at premium prices. Interviewee 1 also gives an example where harvesting complexity terminated a CWS project: *"A high leading forest guy in one of these large companies was telling me the difficulty with this kind of system [CWS] is when you take the standards out, you have a lot of damage to the coppice, so they said that this was complicated, so they stopped doing it".* Inflexibility and efficiency of Eucalyptus monoculture harvesting by big companies was explained by interviewee 3: *"Harvesting today is kind of like, it's a kind of factory, it's an in-line production. […] So it's all mechanised, all homogenised, all standardised".* However, small-scale farmers also face operational obstacles that hamper the implementation of alternative approaches. They would need technical assistance and training, the provision of seedlings

and extra workforce to learn about and apply new silvicultural systems. *"Forest management in this way takes time, takes management, it takes planning, it takes a lot of elements to build that. And I don't think that's a reality for most of the small and medium farms*", as expressed by interviewee 13. The needed planning addressed in the previous quote reflects the barrier of required time management skills to successfully implement mixed species or uneven-aged plantations. Different species are planted for multi-purposes and show varying growth rates. It requires excellent knowledge and experience to develop a feeling for the right planting and harvesting times as well as the right moment for the application of fertilisers (interviewees 3 & 8). The pulp mills also have difficulties adapting to mixed tree plantations, as they need homogeneous wood to ensure a certain wood quality. The mills are precisely adjusted to one Eucalyptus genotype and are therefore not flexible enough to also process acacia wood, which would also be suitable for pulp production.

Another scarce resource is available land to establish new plantation areas. Therefore, the pulp industry follows the approach of land sparing instead of land sharing. This means it focuses on highly efficient production at its plantation sites and, at the same time, sets aside purely natural forest areas with native species to compensate for its intensive land management. The industry argues that it would need to expand its plantation frontiers if it were to establish mixed species plantations in order to achieve the same production capacity as with monocultures. Interviewee 14 explained it as follows: *"The idea is that if we can produce much more wood in the same area, we are not going to use land that is going to be for, I don't know, conservation".*

Interview partners mentioned that missing financial funds and subsidies would be needed to allow risk-free exploration of alternative management systems. Especially small-scale farmers need economic support, as *"they normally lack the money for really basic things. So to develop a new forest project, you need some capital to start that and the return will be in the long term"* (interviewee 11). Rural farmers also do not have access to knowledge about how to unlock existing funds (interviewee 13). Also, bigger landowners would need economic incentives to consider alternatives, as interviewee 11 addressed: *"We normally target smaller landholders, because they need more incentives, but I think it's also important to give subsidies to projects, big projects also with Eucalyptus that embrace biodiversity".* Lastly, governmental funds mainly focus on the agricultural sector, which enjoys a powerful position in Brazil. Therefore, there is a need for better cooperation between the forest and agricultural sector to make funds available for a broader range of industry players, including forest plantation owners (interviewee 13).

Certification hurdles for small-scale farmers are perceived to be quite strong. About ten years ago, the pulp and paper industry followed the market demand for certified wood and supported farmers financially and technically to become FSC certified. However, a few years ago, the market started to

accept non-certified wood, so the companies stopped their support. As a result, more than 500 farms lost their sustainable forest management certifications, which were supposed to be a driver for new standards and thus innovative silvicultural approaches that support ecosystem services (interviewee 10).

4.4.3.7 F7 – Counteract Resistance to Change/Legitimacy

The lack of legitimacy for innovative plantation management concepts is reflected in the lack of awareness of the negative environmental impacts of monocultures and the missing pressure on the pulp and paper industry to change something. Absent pressure is most frequently addressing customers, but the role of society as a whole is also highlighted and scored as a strong barrier to change. Resistance to change can be represented by a very strong corporate paradigm of the pulp and paper industry holding on to monocultures.

Table 15: Barriers F7

Barrier name	Number of interviewees mentioned	Average score [1-4]
Missing pressure from pulp and paper customers to change	12 (75%)	2.8
Missing awareness & pressure from society to change	7 (44%)	3.11
Corporate paradigm, force of habit with Eucalyptus monocultures	7 (44%)	3.5
Focus on technologies of industry plants and Eucalyptus genotypes but not on changing plantation management	5 (31%)	3
Missing awareness of biodiversity benefit for society	4 (25%)	1.66
Lacking FSC stringency and power	3 (19%)	4

Brazilian customers prioritise cheap products, China (a highly important export country) also does not care about sustainability impacts (interviewees 15 & 4). Only European and American clients slowly start questioning sustainability more (interviewee 4), although “they only look if it is certified, then it's good” (interviewee 2). Interviewee 7 stressed the importance of missing pressure from pulp and paper customers as follows:

“If the big guys don't ask us to change, we are not going to change, as you said FSC is OK with that, the government is OK with that, our customers so far are fine with that. So we need this kind of pressure. Big companies, our bigger partners, like consumers, as I said, like Unilever, Nestlé. They need to ask us to change it and then we are going to change.”

Missing pressure from the society in Brazil is very present for interviewee 7, he stated: “Brazil so far as a society is OK with monoculture. The only guys who are concerned about Eucalyptus monoculture,

people like environmentalists, and our neighbourhood, people that are suffering the impact every day, like water, for example. But I mean, it's like 10 percent of our neighbourhood, less than that." This lack of interest or awareness could be justified by the population having to deal with more pressing problems: "I believe that they don't understand very well the depth of the trouble. Because here in Brazil, we have, unfortunately, we have other troubles, other problems to deal with. Unfortunately, few people understand the importance of this kind of problem in Brazil" (interviewee 4). Four interviewees addressed the missing awareness of society about the benefits of biodiversity as a reason for lacking societal demand for more diverse plantations. For the innovative business model to spread and persist, it needs awareness and acceptance of the society, as explained by interviewee 13:

"The challenge in the long term is how to guarantee the long persistence of this forest. With the society recognising the value, and that can be by products. Because otherwise we're going to have a huge challenge in future. I don't want to have forest regeneration and society is left behind and doesn't have a value for them. Otherwise they're going to cut, because society is not going to get a connection with that. So this has to be one part of the solution."

Another very strong barrier contributing to lacking legitimacy for alternatives is the decreasing power of FSC. The organisation is certifying Eucalyptus monocultures and not differentiating between different management models. Interviewee 13 explained the loss of power as follows: *"FSC was created for tropical forest and didn't deliver any impact on that".* He further stated: *"They [pulp and paper companies] said they are getting the same impacts with their work without FSC"*, giving the certification less relevance for the development of sustainable forest management.

A very strong barrier to change is the corporate force of habit. The pulp and paper industry has an intensive focus on their profit-driven business way of managing Eucalyptus plantations. Therefore, forest management needs to be the simplest way possible (interviewee 1). Interviewee 12 framed the resistance to change as a conscious decision, addressing knowledge availability and power relations:

"Access to knowledge is no barrier, but utilising the knowledge, then, is a different thing. […] It's like being big, dominant, and especially like in some regions, knowledgeable about alternatives, and so if they wanted, they could mobilise to change. […] They don't want to diversify, even if that would bring more wealth. And wealth in many senses, like maybe financially but also environmentally, and that would benefit others. It's also that view, like profit for me alone".

A barrier related to the corporate mindset is the continuous focus on Eucalyptus genotype development and technological improvement of monoculture management. Interviewee 2 described a meeting with industry representatives, where he suggested mixed plantations in the North of Brazil

to adapt to climate change. His colleague answered: “Oh no! We will find clones adapted”. Hence, experience with alternative species and management approaches is very limited (interviewee 4).

5 Discussion & Conclusion

In this chapter, the results of this study are discussed to answer the research questions, followed by a reflection on the system innovation approach, sustainable business model innovation theory, and research methods. Furthermore, it discusses managerial and policy implications and concludes with limitations of the study and suggestions for further research.

The goals of this study were (1) to explore costs and benefits of sustainable business model innovation through changing Eucalyptus management towards an increased ecosystem services provision in the Atlantic Forest of Brazil and (2) to identify barriers that may hamper such an innovation on a system (macro) and firm (micro) level. Therefore, a comparative business model analysis of the currently applied commercial short-rotation Eucalyptus monoculture management and the following potential alternatives was conducted: (1) uneven-aged Eucalyptus monoculture in form of a coppice with standards system; (2) mixed species plantation with Eucalyptus and nitrogen-fixing Acacia tree species; and (3) mixed species plantation with Eucalyptus and native tree species. Subsequently, an analysis of the barriers to Sustainable Business Model Innovation (SBMI) of implementing the alternative approaches was performed based on the Technological Innovation System (TIS) framework by Hekkert et al. (2007). The TIS provides a set of seven innovation system functions (*see Table 3* that need to be fulfilled for emerging innovations to diffuse. The data was collected through literature research and interviews with stakeholders across the Eucalyptus supply chain.

The analysis of the widely applied conventional business model showed a focus on high wood productivity outcomes to sell Eucalyptus pulp and paper for a competitive price on the national and international market. The studied alternative business models are mostly presenting an improved provision of ecosystem services such as biodiversity of fauna and flora, however none of those models could compete with the short-term financial profitability implied by the current regime and as such were not implemented by businesses after experimentation. Forrester and Bauhus (2016, p. 57) explained the findings of this research with the regional and managerial characteristics of Eucalyptus monocultures in the Atlantic Forest region: “*Species or structural diversities cannot increase the productivity of very efficient stands that are already at or near the physiological optimum and where a number of the benefits from mixed-species stands are addressed through management inputs such as fertilisers and control of weeds and pest species*”. This lagging productivity of species or structural diversity compared to even-aged Eucalyptus monocultures contradicts global patterns of increased wood biomass in mixed plantings or uneven-aged Eucalyptus stands (Brockerhoff et al., 2013).

The lacking financial competitiveness of alternatives in the Atlantic Forest represented the key blocking mechanism to implementing Eucalyptus SBMI. This barrier was reinforced by the focus on short-term profitability of the pulp and paper industry and ultimately led to failed projects with different approaches, represented by function (F) 1 'Entrepreneurial Experimentation and Production' of the TIS model. Doubts about alternative systems are further increased by lacking research about financial profitability and ecological impacts of alternative systems (barrier to F2 'Knowledge Development'). Higher production costs of sustainable production could be compensated for by adding a price premium for complying to sustainability standards (Yokessa & Marette, 2019). However, the FSC label for responsible forest management does not differentiate between management approaches and therefore does not promote the discussed alternative Eucalyptus production methods (barrier to F5 'Market Formation'). Furthermore, stakeholder participation in creating the FSC regulations is lagging, since a large part of the international market accepts non-certified wood, which is decreasing the legitimacy of the standard (barriers to F3 'Knowledge Exchange' & F7 'Counteract Resistance to Change/Legitimacy').

Yokessa and Marette (2019) suggest to complement eco-labels with governmental regulations and subsidies supporting potential alternatives. However, interviewees reported lacking enforcement of the Forest Code in Brazil (barrier to F4 'Guidance of the Search'), missing governmental subsidies and lacking technical assistance to support more sustainable Eucalyptus management (barrier to F6 'Resource Mobilisation'). Furthermore, there is a lack of market infrastructure for wood products from Acacia and native species as well as for ecosystem services from alternative forest plantations (barrier to F5). Many barriers can be drawn back to legitimacy for change, as Montenegro de Wit and Iles (2016) emphasised that a successful transition to sustainable management requires legitimacy and hence support by scientific, political, economic and civil society actors. Stronger pressure from pulp customers and society would urgently be needed to change the commercial monoculture regime which is embedded in the dominant neoliberal paradigm of short-term cost-effectiveness through high productivity (Kröger & Nylund, 2012).

The SBMI was categorized to be in the pre-development phase of innovation since there is no working prototype of alternative plantation systems that is applied by the pulp and paper industry. For exploring the innovation system in this phase, Hekkert et al. (2011) suggested focusing on the interactions of functions F2 'Knowledge Development', F3 'Knowledge Exchange', F4 'Guidance of the Search', and F6 'Resource Mobilisation'. Most relevance should be given to F2, since learning by searching and doing is a prerequisite for success within innovation systems (Hekkert et al., 2007). However, the barrier analysis showed that all functions contributed greatly to the lock-in of business model innovation. The highest barrier scores were given to F7, which could be explained by the

considerable importance of legitimacy for sustainability-oriented innovations, as these often encounter hesitation and doubt from potential users (Weiss & Nemeczek, 2021). Other strongly perceived functions were F1 'Entrepreneurial Experimentation and Production', and F5 'Market Formation', which is contradicting Hekkert et al. (2011) who expected F1, F5, and F7 to be less influential in the pre-development phase. Other studies using the TIS framework to analyse sustainable innovations also reported deviating function relevances compared to the expectations from Hekkert et al. (2011) in the pre-development phase. Corsatea (2014) identified F1 and F2 to be critical for the marine energy emergence in Europe, and Sawulski et al. (2019) concluded F2 has less of an impact whereas F1 and F3 are crucial for offshore wind in Poland in this first innovation development phase.

This study addressed the missing connection between firm level (micro) and system level (macro) theory for transitions towards innovative business models, answering the call of Reike et al. (2017) to combine business model innovation analysis with the TIS framework. The barrier analysis allowed both to identify business internal challenges as well as innovation inertia caused by the sociotechnical system the firm operates in. Based on the results of this study the following recommendations for using TIS to analyse sustainable business model innovation can be made: Due to the contradictions between the expected and the identified influence of function barriers, it is suggested to take an exploratory approach when applying the TIS framework, as all functions could represent relevant barriers paralyzing innovation. Furthermore, as done in this study, it is advisable to check the quality of data interpretation concerning function barriers with interview partners to increase the validity of data analysis when conducting qualitative research.

Recommendations to policy makers and practitioners in the field can be drawn from the business model and barrier analysis of this study to spur sustainable business model innovation of the Brazilian Eucalyptus industry. First, the unequal level playing field could be addressed by favourable tax schemes and subsidies for an increased provision of ecosystem services to make sustainable practices cost effective. Such policy interventions should be consistent and reliable to enable long-term success. Revenues from payment for ecosystem services also could provide an option to compensate for less productive Eucalyptus management systems. In this regard, control mechanisms such as the Verra certification standard for carbon sequestration are crucial to secure a sustainable provision of ecosystem services, looking holistically at forest management impacts. Second, alliances across stakeholders of wood production from forest plantations could facilitate finding industry partners and customers for alternative wood products or services that result from the studied alternative Eucalyptus management approaches. Valuable starting points are represented by organisations such as the 'Forest Dialogue' or the 'Brazilian Coalition for Climate, Forests and Agriculture' (May et al., 2016). Third, awareness raising campaigns about impacts of the conventional management approach, its

vulnerability to climate change and the relevance of biodiversity for the society as a whole could increase the demand for sustainably grown wood products and put pressure on the pulp and paper industry to extend its focus from a profit-driven value proposition to also include the provision of ecosystem services as core value they share with their customers.

The first limitation of the study is the sample size of interview partners for the quantitative barrier analysis. However, it gave a first impression on the strength of the mentioned challenges. Moreover, the average length of the interviews of more than one hour gave the opportunity to gain in-depth insights of the potential of alternative management approaches and their blocking mechanisms. Unfortunately, both literature and interview partners could not provide sufficient information of the financial aspects of alternative management systems to make a detailed cost-benefit analysis, which represents the second limitation. Third, the study focused on ecological and economic impacts of conventional and alternative business models, neglecting social aspects such as job loss or generation through business model innovation.

Since it was not possible to obtain sufficient financial data on the alternatives, potential future field research could focus on monitoring or modelling economic costs and benefits in the long-term, taking into account potential revenues from ecosystem services provisioning and longer rotation cycles of native wood that can be sold at premium prices. Moreover, ecological impacts of alternatives were not measured in detail in field research of previous studies and would require further investigation to increase credibility of the alternative Eucalyptus management options. Lastly, it would be interesting to explore barriers from the perspective of small-scale Eucalyptus farmers in more detail. Their position was underrepresented in this research and probably unveils different challenges compared to the pulp and paper industry.

This thesis concludes with a call for action to the pulp and paper companies in Brazil, inspired by the answers of interview partners when they were asked about their personal advice for the industry at the end of the interviews.

Many interview partners addressed risk of decreased wood growth productivity and hence risk of financial loss as barriers to implementing alternative approaches. However, the focus on short-term profitability could distract from potential long-term success with alternatives approaches and their diverse products and services. Monocultures are vulnerable to climate change and pests, both challenges will only grow in future - isn’t it a higher risk not to explore sustainable business model innovation for Eucalyptus plantations?

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7 Appendices

7.1 Appendix A: ForCES certification for ecosystem services

The following provides a brief overview of the ecosystem services eligible for ForCES certification and the steps that need to be taken during the certification process. More detailed information is available in the following guides published by FSC: 'FSC-GUI-30-006 V1-0 EN' and 'FSC-PRO-30-006 V1-2 EN' which can be accessed via https://fsc.org/en

The ForCES tool by FSC allows a certification of the following ecosystem services:

- carbon sequestration and storage
- biodiversity conservation
- watershed services
- soil conservation
- recreational services.

Landowners can only apply for a ForCES certification if they already hold the FSC certification. There are specific management requirements that need to be fulfilled to obtain a ForCES certification, e.g. wetlands, peatlands, savannahs, and natural grassland areas are not allowed to be converted in forest plantations. Other management requirements are tailored to the ecosystem service that is aimed to get certified. To demonstrate the impact on ecosystem services provision through forest management, 7 steps have have to be followed:

1. Identification of ecosystem service type for certification
2. Description of ecosystem service (condition, threats, etc.)
3. Choosing which management actions can be taken to support ecosystem service (e.g. restoration activities)
4. Selection of outcome indicator to measure ecosystem service (e.g. natural forest cover)
5. Selection of appropriate methodology to measure ecosystem service (e.g. amount of deadwood for biodiversity conservation)
6. Measurement of ecosystem service and demonstration comparison to previous values or reference sites
7. Reporting maintenance/conservation/restoration/improvement of ecosystem service

(Forest Stewardship Council, 2021)

7.2 Appendix B: Interview Guide Examples for Researcher & Industry Stakeholder Groups

Interview Guide for Mixed species plantation management with Eucalyptus and Acacia

Interviewee: XX

Interviewer: Miriam Bellink

Date: XX

Overview Master thesis topic

Problem statement: Brazil aims to reforest an area of around 21 million hectares. Reforestation with native species offers habitats for highly diverse species but to the cost of high implementation costs and with no short-term economic return. Another option for reforestation are highly productive and profitable eucalyptus monocultures, but these have a high water consumption and offer a very limited biodiversity potential within the plantations.

Research: Ecological and economic potential of alternative eucalyptus plantation management approaches. Subsequently identifying organisational and systematic barriers for changing the conventional monoculture business models. Alternative management options taken into account are: 1. Mixed species plantations with Eucalyptus and Acacia; 2. Mixed species plantations with Eucalyptus and diverse native tree species; 3. Coppice with standards (two-layered forest of Eucalyptus over- and understory).

Interview questions

Introduction

1. Short introduction Miriam Bellink
2. Short introduction Interviewee XX

Ecosystem services

3. What are the positive and negative impacts on ecosystem services from mixed plantations with Eucalyptus and Acacia?

Plantation owners and economic feasibility

4. What is the target group for implementing such new plantation management approaches?

a. What was the research aim of pulp and paper industry partners for field research?

5. Financial analysis of mixed species plantations
    a. Is wood from eucalyptus in mixed species plantations the main source of income? What is the function of Acacia?
    b. Do you think a mixed species plantation with Eucalyptus and Acacia is an economically attractive option for plantation owners compared to Eucalyptus monocultures?
    c. To estimate the cost structure of a mixed species plantation of Eucalyptus and Acacia I would need some more information. Do you have data about the following points?
        i. Seedling costs for E. grandis and A. mangium
        ii. Quantity of wood (Eucalyptus and Acacia) harvested at end of cutting cycles at Brazil research sites
        iii. Estimated sale price for Eucalyptus and Acacia
        iv. Costs for fertiliser that is still needed at mixed plantations

    d. Can the following costs be assumed to be similar to conventional eucalyptus monocultures? If not, do you have data for it or know where I could get it from?
        i. Implementation costs (site preparation, fencing, tree planting)
        ii. Maintenance costs (weeding, control of leaf-cutter ants, herbicides if used)
        iii. Logging costs

Barriers

6. What are current barriers for the implementation of alternative eucalyptus plantation management options?
   Would you please give the barriers you mention a value from 1 (no or slight barrier) to 4 (very strong barrier) according to how strongly you perceive them?

To get an impression of the topics I would like to discuss, see the following points:

a. Governmental regulations
    i. Is there a lack of legal regulatory frameworks that enhance the sustainability of forest plantations?
    ii. Is there a lack of encouragement to innovativeness? (e.g. Government subsidies for alternative plantation management?)
    iii. Is there a lack of involvement of stakeholders in decision making for regulations and industry standards?

b. Market & Finances
    i. How effective are currently used voluntary market standards? (e.g. FSC certifies eucalyptus monocultures)
    ii. How effective and successful do you think a Payment for Ecosystem Services could be to support alternative eucalyptus plantation options?
    iii. Do you think that missing knowledge and expertise of plantation owners form a barrier to alternative plantation options?
    iv. Enterprise culture: Do you think there is a lack of motivation to change the business model, also connected to the profitability of the existing business model?
    v. Do you think that the financial risk, short-termism of alternative approaches form a barrier?

c. Behavioural and Social factors of stakeholders
    i. Do you think there is a lack of consumer acceptance/demand for alternative plantation management options? Is there a lack of awareness of sustainability impacts of short-rotation eucalyptus monocultures?
    ii. Do you think there is not enough stakeholder pressure for alternative plantation management options?

7. Based on your research, would you advise businesses such as Suzano to implement alternative plantation management options such as a mixed plantations with Eucalyptus and Acacia in Brazil? If yes, what would your arguments be? If no, why not?

Closing

1. Do you have any questions?
2. Are there any comments or issues you would like to share?
3. Who else would be interesting to reach out to for my research? Could you provide me with some contacts?

Interview guide for alternative eucalyptus plantation management

Interviewees: XX

Interviewer: Miriam Bellink

Date: XX

Overview Master thesis topic

Problem statement: Brazil aims to reforest an area of around 21 million hectares. Reforestation with native species offers habitats for highly diverse species but to the price of high implementation costs and with no short-term economic return. Another option for reforestation are highly productive and profitable eucalyptus monocultures, but these have a high water consumption and offer a very limited biodiversity potential within the plantations.

Research: Ecological and economic potential of alternative eucalyptus plantation management approaches. Subsequently identifying organizational and systematic barriers for changing the conventional monoculture business models. Alternative management options taken into account are:

1. Mixed species plantations with Eucalyptus and diverse native tree species;
2. Mixed species plantations with Eucalyptus and Acacia;
3. Coppice with standards (two-layered forest of Eucalyptus over- and understory).

Interview

Introduction

1. Short introduction Miriam Bellink
2. Short introduction Interviewee XX

Suzano's Business Model & Sustainability efforts

1. What does the current business model of Suzano look like? (In terms of which values are created, e.g. pulp, ecosystem services; how the values are created and how these values are captured)
2. Why is Suzano engaging in research about alternative plantation management systems? E.g. mixed species plantation systems of Eucalyptus with Acacia, and Eucalyptus with native tree species *(for more information scroll down to the end of the interview guide).*

a. Is Suzano aiming to change its business model based on research about alternative plantation systems?

b. How much area (in ha & percentage) of Suzano is covered by alternative eucalyptus plantations (not short-rotation monocultures)?

3. Do you think a mixed species plantation with Eucalyptus and Acacia or native tree species could be an economically attractive option compared to Eucalyptus monocultures?

Barriers

1. What are current barriers for the implementation of alternative eucalyptus plantation management options (such as mixed plantations with Eucalyptus and Acacia or native tree species or the Coppice with standards silvicultural system)?

   Would you please give the barriers you mention a value from 1 (no or slight barrier) to 4 (very strong barrier) according to how strongly you perceive them?

To get an impression of the topics I would like to discuss, see the following points:

a. Governmental regulations
   i. Is there a lack of legal regulatory frameworks that enhance the sustainability of forest plantations?
   ii. Is there a lack of encouragement to innovativeness? (e.g. Government subsidies for alternative plantation management?)
   iii. Is there a lack of involvement of stakeholders in decision making for regulations and industry standards?

b. Market & Finances
   i. How effective are currently used voluntary market standards? (e.g. FSC certifies eucalyptus monocultures)
   ii. How effective and successful do you think a Payment for Ecosystem Services could be to support alternative eucalyptus plantation options?
   iii. Do you think that missing knowledge and expertise of plantation owners form a barrier to alternative plantation options?
   iv. Enterprise culture: Do you think there is a lack of motivation to change the business model, also connected to the profitability of the existing business model?

v. Do you think that the financial risk, short-termism of alternative approaches form a barrier?

c. Behavioural and Social factors of stakeholders
   i. Do you think there is a lack of consumer acceptance/demand for alternative plantation management options? Is there a lack of awareness of sustainability impacts of short-rotation eucalyptus monocultures?
   ii. Do you think there is not enough stakeholder pressure for alternative plantation management options?

Closing

1. Do you have any questions?
2. Are there any comments or issues you would like to share?
3. Who else would be interesting to reach out to for my research? Could you provide me with some contacts?
   a. Pulp customers (preferably based in Europe), Contacts with governmental bodies in Brazil; NGOs that are busy with plantation management in Brazil; FSC or PEFC.

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4. *EXTRA INFORMATION Question 4.*

Information about Suzano research involvement about mixed species plantations:

- Eucalyptus with native tree species
  - Links to articles (PDFs provided in email attachment):
    - https://www.researchgate.net/publication/323880431_High_diversity_mixed_plantations_of_Eucalyptus_and_native_trees_An_interface_between_production_and_restoration_for_the_tropics
    - https://www.researchgate.net/publication/335934410_Exotic_eucalypts_From_demonized_trees_to_allies_of_tropical_forest_restoration
  - Contribution: Field work support
  - No contact person of Suzano given

- Eucalyptus with Acacia
  - Link to article (PDF provided in email attachment)

        - https://www.researchgate.net/publication/257197904_Eucalyptus_and_Acacia_tree_growth_over_entire_rotation_in_single-_and_mixed-species_plantations_across_five_sites_in_Brazil_and_Congo
    - Contribution: Field work support
    - Contact Suzano: José Luis Gava