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From extraction to commercialization: an analysis of the timber supply chain in the brazilian legal amazon

Da extração à comercialização: uma análise da cadeia produtiva da madeira na amazônia legal brasileira

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Dejanir José de Souza[1]
https://orcid.org/0009-0006-9426-4569
http://lattes.cnpq.br/5919617369321826
Instituto Federal do Acre, AC, Brazil
E-mail: dejanirjosedesouza@gmail.com

Rodrigo Duarte Soliani[2]
https://orcid.org/0000-0003-3354-6838
http://lattes.cnpq.br/0533333224235259
Instituto Federal do Acre, AC, Brazil
E-mail: rodrigo.soliani@ifac.edu.br

Francisco Bezerra de Lima Junior[3]
https://orcid.org/0000-0003-3170-5145
http://lattes.cnpq.br/3124252504596545
Instituto Federal do Acre, AC, Brazil
E-mail: francisco.junior@ifac.edu.br

Pollyana Rufino de Souza Oliveira[4]
https://orcid.org/0000-0002-2336-3010
http://lattes.cnpq.br/5652244141662808
Instituto Federal do Acre, AC, Brazil
E-mail: pollyana.oliveira@ifac.edu.br

Thais Diniz Reis Drumond[5]
https://orcid.org/0000-0001-6043-8416
http://lattes.cnpq.br/4483923418150624
Instituto Federal do Acre, AC, Brazil
E-mail: thais.drumond@ifac.edu.br

[1] Logistics Technologist from the Instituto Federal do Acre, IFAC, Brazil.
[2] Production Engineer from FIEL. Master's in Administration from UNIMEP. Doctorate in Environmental Technology from UNAERP. Postdoctorate in Production Engineering and Systems from UFPB. Currently, he is a professor at the Instituto Federal do Acre, IFAC, Brazil.
[3] Economist from UFAC. Master's in Regional Development from UFAC. Currently, he is a professor at the Instituto Federal do Acre, IFAC, Brazil.
[4] Bachelor's in Administration from UNIVERSO. Specialist in Foreign Trade and International Business from INPG. Master's in Professional and Technological Education from IFAC. Currently, she is a professor at the Instituto Federal do Acre, IFAC, Brazil.
[5] Bachelor's in Administration from Centro Universitário Newton Paiva. Specialist in Strategic Human Resources Management from CEFET/MG. Master's in Administration from Centro Universitário UNA. Currently, she is a professor at the Instituto Federal do Acre, IFAC, Brazil.

Abstract
The production chain of the Brazilian forestry sector plays a crucial role in the global economy, providing a wide variety of products used in construction and industrial processes. The extraction of timber from native forests is essential for the production of paper, furniture, and charcoal, driving the economy through exports. However, the expansion of this sector faces challenges related to the lack of environmental conservation policies, infrastructure, financing, and the pressure of illegal deforestation. This article aims to enhance the description of the timber production process in the Brazilian Legal Amazon region, addressing its stages, procedures, and necessary considerations for sustainable extraction in accordance with environmental laws. A case study was conducted in a timber company in Porto Acre, Acre, involving literature review and a questionnaire administered to the responsible manager. The timber extraction process requires document analysis, legal compliance, and field surveys. Projects are developed to determine which tree species can be harvested, with a priority given to young trees and those with seeds, as well as considering protected areas. After project approval, camps and roads are set up to initiate the exploitation. The logistics involve the construction and maintenance of roads, temporary bridges, and storage yards, utilizing heavy machinery to clear paths, drag logs, and load trucks. The careful placement of storage yards considers biodiversity and ecosystem protection. Through a continuous commitment to responsible forest management, it is possible to reconcile economic activity with nature conservation, ensuring a sustainable future for native forests.

Keywords: Production chain. Wood. Extraction. Forest management. Sustainability.

Resumo
A cadeia produtiva do setor florestal brasileiro desempenha um papel fundamental na economia global, fornecendo uma ampla variedade de produtos utilizados na construção civil e processos industriais. A extração de madeira em florestas nativas é um processo essencial para a produção de papel, móveis e carvão, impulsionando a economia por meio da exportação. No entanto, a expansão desse setor enfrenta desafios relacionados à falta de políticas de conservação ambiental, infraestrutura, financiamento e pressão do desmatamento ilegal. Este artigo tem como objetivo aprimorar a descrição do processo de produção da madeira na região da Amazônia Legal brasileira, abordando suas etapas, procedimentos e considerações necessárias para uma extração sustentável em conformidade com as leis ambientais. Um estudo de caso foi realizado em uma empresa madeireira no município de Porto Acre, Acre, envolvendo revisão da literatura e aplicação de um questionário ao gerente responsável. O processo de extração de madeira requer análise documental, conformidade legal e levantamento de campo. Projetos são elaborados para determinar quais espécies de árvores podem ser cortadas, priorizando as jovens e as que têm sementes, além das áreas de proteção. Após a aprovação dos projetos, acampamentos e estradas são montados para iniciar a exploração. A logística envolve a construção e manutenção de estradas, pontes temporárias e pátios de armazenamento, com o uso de máquinas pesadas para abrir caminhos, arrastar toras e carregar caminhões. A localização cuidadosa dos pátios de armazenamento leva em consideração a biodiversidade e a proteção do ecossistema. Por meio de um compromisso contínuo com o manejo florestal responsável, é possível conciliar a atividade econômica com a conservação da natureza, assegurando um futuro sustentável para as florestas nativas.

Palavras-chave: Cadeia produtiva. Madeira. Extração. Manejo florestal. Sustentabilidade.

1. Introduction

The forestry sector's production chain plays a pivotal role in the global economy by offering a diverse range of products utilized in both the construction industry and industrial manufacturing processes (FENG; AUDY, 2020). In Brazil, this economic activity holds particular significance due to the country's vast expanse of tropical forests, which ranks among the world's largest, offering immense potential for the production of forest raw materials (TEIXEIRA et al., 2018). Wood serves as a fundamental raw material in the manufacturing of various products, including paper, furniture, and charcoal, and its exportation serves as a crucial driver for the Brazilian economy (SILVA et al., 2015).

The forestry sector in Brazil exhibits a complex production structure, shaped by the abundance of its native forests and the global importance of the pulp and paper industry, as well as pine and eucalyptus forests (MAXIMO et al., 2022). This structure is a direct reflection of the country's vast territorial expanse, encompassing a diverse range of forest species. The pulp and paper industry serves as a pivotal driver within Brazil's wood production chain, accounting for a substantial share of the consumption of forest raw materials (DE ARAUJO et al., 2017). Moreover, planted pine and eucalyptus forests find application across various industrial sectors, including the manufacturing of pulp, wood panels, furniture, and cardboard (MCDERMOTT et al., 2015). The interrelationships among equipment manufacturers, suppliers, engineering projects, and forestry product companies further contribute to the intricacy of the production structure within Brazil's forestry sector (DE ARAUJO et al., 2020).

The preservation of biodiversity stands as a paramount concern within the forestry sector, as it endeavors to foster the development of sustainable economic practices (BOIRAL; HERAS-SAIZARBITORIA, 2017). Nevertheless, noticeable disparities in income distribution and economic influence prevail, with a handful of major corporations exerting dominance over the production and trade of forest products. Simultaneously, numerous small and medium-sized enterprises encounter challenges when attempting to compete in the market (BASTOS LIMA, 2021).

The structure of the forestry sector in Brazil is marked by diversity, with two distinct organizational models in place. In the first model, which prevails in sectors such as pulp, paper, veneer, fiberboard, and particleboard, a handful of large vertically-integrated companies dominate the production and trade, covering the entire supply chain from the forest to the manufacturing of finished products (SAUTER; SCHEIDING, 2023). In the second model, primarily observed in the production of sawn timber, plywood, and furniture, a significant number of small and medium-sized enterprises operate with comparatively lower entrepreneurial capacity (VÁSQUEZ et al., 2019).

Brazil has emerged as a significant player in the global forest products market, benefiting from its abundant forest resources and the entrepreneurial capabilities of its industry (MAXIR; MASULLO, 2018). Nevertheless, this position faces growing threats due to the mounting challenges encountered by companies in expanding their operations, particularly in the Amazon region (SCHMINK; WOOD, 2019). The extraction of timber from native forests has become the primary economic activity across all states within the Legal Amazon region (comprising Amazonas, Acre, Rondônia, Roraima, Pará, Maranhão, Amapá, Tocantins, and Mato Grosso), ranking third in the export agenda, trailing only minerals (HOMMA, 2014).

The absence of well-defined environmental conservation policies, inadequate infrastructure, and insufficient financing pose significant risks to the sustainability of this growth (PELICICE; CASTELLO, 2021). The lack of effective monitoring and measures to combat illegal deforestation creates pressure on the Brazilian forest

product industry. Pinheiro et al. (2022) argue that tangible conservation measures must be implemented, sustainable forest management practices should be promoted, and policies incentivizing the use of legal and sustainable sources are imperative.

Building upon the provided context, this study seeks to improve the depiction of the timber extraction process from native forests in the Brazilian Legal Amazon region, delving into its stages, procedures, and requisite considerations for sustainable and environmentally compliant practices. To accomplish this objective, a case study was carried out at a timber company situated in the municipality of Porto Acre, within the state of Acre. This approach enables a more meticulous analysis of the sector's challenges, incorporating the nuances, local particularities, and regional obstacles.

2. Theoretical Framework

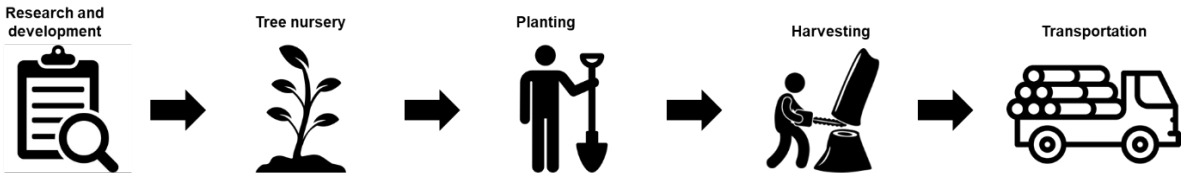
2.1 Wood production chain

A production chain is a dynamic system comprising of various companies that collectively provide products and services to the market, catering to local, regional, and global demands. This interconnected network encompasses input suppliers, rural properties, agribusinesses, processing industries, marketing, and distribution (NAIK; SURESH, 2018; SOLIANI, 2022). Additionally, the production chain incorporates the end consumer and the institutional and organizational framework within which it operates. This intricate system involves the collaboration of multiple stakeholders, working in unison to effectively meet the ever-evolving needs of consumers (GOVINDAN, 2018).

The wood production chain covers every stage involved in supplying products made from this raw material. It encompasses various activities, including forest research and development, seedling production, forest planting and maintenance, as well as wood harvesting, transportation, and storage, both for the industry and the consumer market (NAMBIAR et al., 2018).

According to Ramage et al. (2017), forest production chains encompass a series of processes that transform forest resources into products and services. Each process plays a crucial role in analyzing the production chain. These processes often involve enhancing the value of wood through modifications in its appearance and/or transportation to different locations. Within the wood production chain, processes can span from tree planting and growth to harvesting, transportation, paper production, recycling, energy generation, and more (BAGHIZADEH et al., 2021). Figure 1 provides a simplified illustration of the fundamental stages in the wood production process.

Figure 1: Stages of wood production



Source: Adapted from Simioni et al., 2018

The initial stage involves research and development conducted by institutions such as Embrapa (Brazilian Agricultural Research Corporation) and university research centers. The outcomes of this stage are utilized to provide the necessary inputs to nurseries, which marks the second stage. Subsequently, forest stands are established in the third stage, and harvesting takes place when they reach the desired maturity in the fourth stage. Finally, in the last stage, the wood is transported to its

intended destination. While this schematic provides a simplified overview of the production process, it is important to note that there are other essential components in the wood production chain, including raw material supply, wood processing, and commercialization, which are not depicted in Figure 1.

Inputs play a fundamental role in meeting the demands of forest production, which is responsible for obtaining both wood and non-wood products. Wood products encompass a wide range, including energy, charcoal, sawn timber, pulp, solid wood products, processed wood, and wood residues. These products cater to various sectors such as furniture, paper, steel, domestic consumption, and more, serving both the domestic and international markets (SINGH et al., 2022). On the other hand, non-wood products consist of gums, waxes, rubber, fibers, aromatics, medicinal applications, dyes, and more. These products find applications in sectors such as chemicals, pharmaceuticals, automotive, food, and other industries (AFONSO et al., 2022).

Brazil plays a pivotal role in the global forestry sector, renowned for the extensive expanse of its natural forests and occupying a prominent position in this field. Within this context, the wood production chain serves a vital function, encompassing a range of activities from forest research and development to harvesting, transportation, processing, and commercialization of diverse products. This chain is characterized by its complexity and diversity, which vary depending on the desired end product, such as sawn timber, pulp, or charcoal. To fully grasp this complexity, it is imperative to undertake a meticulous analysis and comprehend the various stages and processes involved. The subsequent section aims to provide pertinent information to foster a comprehensive understanding of the subject matter.

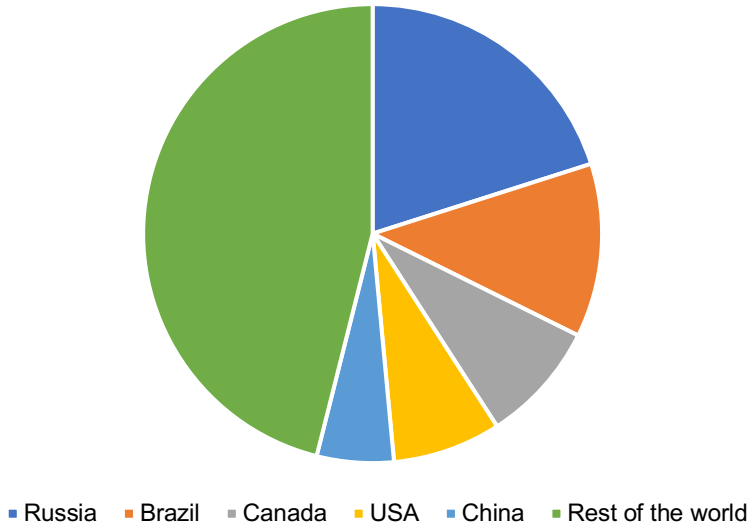
2.1 The significance of Brazil in the global forestry industry

Brazil is globally acknowledged as one of the countries boasting the largest forested areas. According to data from the National Forest Information System (SNIF, 2020), the Brazilian forest area encompasses a staggering 58.5% of the national territory, equivalent to approximately 497,962,509 hectares. Out of these expansive forests, around 98% are comprised of natural forests, with the remaining 2% consisting of planted forests.

In terms of global participation, data from the Food and Agriculture Organization of the United Nations (FAO, 2020) indicate that Brazil holds 57% of the South American forest area and 12% of the total global forest area. These numbers highlight the immense wealth and importance of forests in the country, not only in terms of biodiversity but also as valuable natural resources.

According to the Global Forest Resources Assessment Report (FAO, 2020), which evaluated forest coverage in 236 countries and territories between 1990 and 2020, the total forest cover area in the world amounts to 4.06 billion hectares, accounting for 31% of the planet's total area. The five largest forested areas in the world are found in Russia, Brazil, Canada, the United States, and China, with Brazil having the second-largest forested area at 497 million hectares, as illustrated in Figure 2.

Figure 2: Top five countries with the largest forest coverage in 2020 (Million hectares)



Source: FAO, 2020.

As depicted in Figure 2, Russia, Brazil, Canada, the United States, and China collectively account for more than half of the world's forested areas. Among the global forest coverage, native forests constitute 93%, while planted forests make up 7%, with 45% of the planted forests being intensively managed, primarily for productive purposes (FAO, 2020).

Brazil's native forests encompass three primary biomes: the tropical forests of the Amazon and remnants of the Atlantic Forest, the cerrado forests in the Central Plateau, and the semi-temperate forests in the Southern Region (ABREU et al., 2022). The Amazon biome, spanning a vast area of 4.2 million km2, accounts for 49.3% of the national territory. In addition to its exceptional biodiversity, this biome boasts valuable resources, including extensive reserves of commercial timber and significant carbon stocks. Furthermore, the Amazon is a hub for a diverse range of non-timber forest products that sustain and benefit numerous local communities (SNIF, 2020).

The Amazon Rainforest alone accounts for one-third of the world's tropical forests, boasting the largest reserves of timber products, estimated at approximately 60 billion m³ of logs (DE LIMA et al., 2020). In 2017, according to data from the study by Caires et al. (2019), the extraction of native forests generated a financial turnover of R$ 2.8 billion in timber products within the region. In contrast, silviculture production reached an impressive R$ 13.7 billion, representing a value that is 83% higher than that of timber extraction.

2.2 Silviculture and reforestation

The production of timber logs plays a crucial global role in the construction industry and the furniture sector (BARBU; TUDOR, 2022). The diverse range of coniferous species and tropical woods available characterizes distinct markets with unique functions, pricing, and commercial dynamics. While the United States and Western Europe serve as the main consumer markets, there has been a rapid increase in demand for timber logs in China, fueled by the region's swift economic growth (KE et al., 2019).

Forest activity can be categorized into two primary forms of economic exploitation. As stated by De Araújo et al., 2021, the first form entails the extraction of native forests, which can be conducted extensively, either with or without replenishment efforts. The second form is reforestation, which involves the deliberate planting of forests with exotic species, such as pine and eucalyptus, and to a lesser extent, with native species in the context of Brazil.

Silviculture is the practice of cultivating forests with the aim of producing both timber and non-timber products, such as barks, leaves, and plant gums (CHAMBERLAIN et al., 2018). Reforestation, on the other hand, is a planting technique utilized in commercial forestry and is a key component of silvicultural activities. This process involves the management and production of planted trees to yield various products, including timber, pulp, and other derived materials (IMANUDDIN et al., 2020).

Forest production relies primarily on the cultivation of planted forests, a practice known as silviculture. It involves the deliberate planting of selected commercial tree species to fulfill the demands of the industrial process (RAMANTSWANA et al., 2020). Following the planting phase, meticulous forest management becomes crucial throughout the production cycle, ensuring optimal growth and development. Finally, forest harvesting is conducted in accordance with the desired end product, necessitating careful planning and execution (TONG et al., 2020).

2.3 The Brazilian Forest Code

The Forest Legislation in Brazil encompasses a comprehensive body of laws designed to regulate the exploitation and utilization of forest resources (RORIZ; FEARNSIDE, 2015). Its origins can be traced back to the colonial era, where the initial provisions were established to ensure the appropriate management of vegetation, water, and soil. Over time, these laws have undergone frequent revisions, significantly impacting the stakeholders engaged in environmental area management and monitoring, as well as researchers operating within this domain (CASTELO, 2015).

In this context, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) plays a pivotal role in safeguarding the environment, ensuring sustainable use of natural resources, and promoting environmental quality across the entire national territory, as mandated by Law No. 7.735/1989 (BRAZIL, 1989). However, the vast extent of Brazil's territory imposes a significant burden on IBAMA's oversight activities, necessitating the decentralization of administrative actions. To address this, Law 11.284/2006 was enacted, establishing guidelines for the decentralization of forest management and the transfer of responsibilities from the federal government to the states and municipalities (BRAZIL, 2006).

According to the study conducted by Aamodt (2018), subsequent to that, representatives from rural areas, including farmers and businessmen, with political support from government sectors, initiated discussions on the reform of the primary legal instrument of environmental legislation: the Forest Code (Law 4.771/65). The 1965 law, along with its amendments, established the percentages of the Legal Reserve and the location of Permanent Preservation Areas (PPAs), which limited the land use by producers (BRAZIL, 1965). In its most recent version, the code specified that the Legal Reserve areas should occupy between 20% and 80% of the properties, depending on the region. Along riverbanks, forests were required to be preserved in strips ranging from 30 to 500 meters, based on the width of the watercourse. Proposals for new approaches were presented with the aim of reconciling the country's economic growth with environmental preservation. The divergent interests of the various social

groups involved sparked a contentious debate, particularly between the interests of rural producers and conservationist groups (CASTELO, 2015).

In 2011, the Brazilian National Congress undertook an examination of proposed modifications to the country's Forest Code of 1965, as outlined in Bill 1.876/1999. This bill suggested significant changes that would impact Brazil's agroforestry landscape. Consequently, Law 12.651, commonly referred to as the "New Forest Code," was enacted. This legislation establishes comprehensive regulations aimed at protecting native vegetation throughout Brazil, encompassing PPAs, Legal Reserves, and Restricted Use Areas. Additionally, it addresses issues related to forest exploitation, fire control, and economic instruments (EMBRAPA, 2016). To ensure environmental compliance on rural properties and facilitate the restoration of areas with environmental liabilities, the law also introduced the Rural Environmental Registry (CAR) and the Environmental Regularization Program (PRA).

The "New Forest Code" introduced more flexible rules for the restoration of Legal Reserves and PPAs, particularly benefiting small-scale producers. While the legislation faced considerable criticism from environmentalists upon its approval, the government, the majority of Congress, and the productive sector considered the new rules to be more realistic. This perspective was influenced by the fact that only 20% of farmers had managed to comply with the provisions of the previous law since 1965. The law also acknowledges rural areas that were consolidated before 2008 and establishes criteria for the sustainable use of native vegetation (ALENCAR, 2016).

Family farmers and small rural landowners benefit from tailored regularization rules based on property size measured in fiscal modules, applicable to both PPAs and Legal Reserves. The discussions surrounding the New Forest Code brought about significant changes in deforestation rates within the Legal Amazon region during the first decade of the 2000s. These transformations are closely tied to the government's heightened efforts to combat deforestation and preserve the region's invaluable natural resources (DA CRUZ et al., 2021).

2.4 The wood industry sector

The wood industry sector exhibits a remarkable level of diversification, encompassing a wide range of production processes and supply chains. As a result, it becomes challenging to make sweeping generalizations about the sector as a whole. Within this context, this discussion aims to outline the distinct segments within the processing and refining industries that deal with forest raw materials. These segments are responsible for converting wood into various products, including pulp, paper, wood panels, sawn wood products, biomass, and bioenergy. Each segment possesses its own unique characteristics, specific processes, and technologies. Additionally, they operate within distinct markets with varying demands. Gaining a comprehensive understanding of these segments is crucial for comprehending the functioning of the forestry industry and recognizing its significant contributions to both the economy and the environment.

Companies engaged in the steel and energy sector play a significant role in producing firewood, charcoal, and wood chips for domestic and industrial use, as well as for export (BRACK, 2017). The growing imperative to replace fossil fuels in order to preserve the environment and mitigate global warming has propelled the adoption of renewable energy sources. Consequently, harnessing forest biomass for energy production offers multiple benefits. It not only aids in reducing greenhouse gas emissions but also fosters socio-economic development in rural areas by promoting

production diversification and establishing a secure, diversified energy market (GIODA, 2019).

Sawmills play a crucial role in the wood industry and the overall economy, as they are responsible for converting wood into value-added products like boards, planks, and beams used in construction, furniture, and various other applications (DANGEL, 2019). These companies exhibit a diverse range of sizes, categorized as large, medium, or small sawmills. Large-scale sawmills typically possess high production capacity and employ advanced technology, whereas medium and small sawmills tend to concentrate on specific market segments, such as producing high-quality wood for furniture or catering to local clientele (LI et al, 2016).

In the pulp and paper sector, activities encompass the production of graphic and editorial products, packaging, as well as export and domestic, industrial, and commercial consumption (LI et al., 2021). The production chain of pulp involves wood production and industrial activities such as chipping (conversion of wood into chips), cooking, purification, and drying of wood pulp. Subsequently, the final products are packaged, marketed, and consumed, involving suppliers of services and inputs for the industry (BAJPAI, 2015).

2.4.1 Wood transformation

The products derived from solid wood undergo an initial process known as log breakdown, which is also referred to as primary processing or the first transformation of wood (NASIR; COOL, 2020). Log breakdown entails extracting different pieces from the log after the tree has been felled and shaping them into appropriate sections for various applications, including boards, beams, slats, rafters, and battens (COSTA et al., 2020). This process yields a diverse range of products that serve distinct purposes.

Laminated wood is manufactured by subjecting logs to a process of cooking and subsequently cutting them into thin layers, primarily for decorative purposes (DANGEL, 2019). Wood intended for long-lasting applications like furniture, roof structures, and decks needs to undergo a treatment process. This treatment and preservation process aims to enhance the wood's durability and prolong its lifespan, safeguarding it against fungal and insect damage (OLORUNNISOLA, 2018).

The wood transformation process is a stage that adds significant economic value to the final product and allows for meeting specific consumer needs (APPELHANZ et al., 2016). With the scarcity and increasing cost of solid wood, the use of processed wood has become increasingly common, enabling the utilization of less valuable wood species and their by-products. In this industrial process, reconstituted panels such as particle boards, medium-density fiberboards (MDF), fiberboards, oriented strand boards (OSB), and plywood are obtained (WEBER; IWAKIRI, 2015). These products are widely used in various sectors, including construction, furniture manufacturing, flooring, and other applications.

As highlighted by Winans et al. (2017), the use of wood residues is a notable practice in diverse industries, including those reliant on forest resources. These materials are regarded as by-products and are effectively employed throughout the production chain, with the dual purpose of minimizing environmental impact and enhancing industrial efficiency.

In the wood industry, the residues produced during mechanical wood processing, such as bark, offcuts, and sawdust, are employed for combustion in boilers to generate steam. This steam is used in the wood drying process, or in furnaces to produce hot gases or heat thermal fluids (LUO; ZHOU, 2022). Additionally, the

chipping process of these residues is commonly employed and has demonstrated a growing market.

3. Methodology

The wood production chain holds a prominent position as one of Brazil's oldest and most crucial economic activities, contributing significantly to the country's development, job creation, and income generation (DE ARAUJO et al., 2017). Inspired by this, the purpose of this study is to comprehensively examine the wood production chain by conducting a case study on a timber company situated in Porto Acre/AC. To accomplish this objective, an extensive literature review was undertaken, accompanied by the administration of a semi-structured questionnaire to the company's manager, who bears the responsibility for its operations.

Literature review is one of the most crucial stages in any scientific research, as it enables the researcher to assess what has already been written on the topic at hand, identify knowledge gaps, and thus define the approach to be adopted with greater clarity (SNYDER, 2019).

In conducting this study on the wood production chain, the literature review was carried out in three stages. Firstly, a comprehensive bibliographic search was conducted in the Scopus, Web of Science, and SciELO databases, utilizing the keywords: "Production chain" AND "Wood" AND "Forest management" OR "Extraction" AND "Wood" AND "Logistics." The search was limited to studies published between 2006 and 2023, aiming to provide a comprehensive and current understanding of the research landscape. This inclusive approach encompasses relevant studies, advancements, and developments over a significant period of time, including publications in both Portuguese and English languages.

Subsequently, the titles and abstracts of the identified studies were assessed, applying criteria for inclusion and exclusion. The selected studies were expected to address pertinent aspects pertaining to the understanding of the wood production chain, including forest management practices, extraction technologies, transportation processes, storage and marketing, as well as issues concerning the sector's sustainable development. Studies that did not meet the inclusion criteria or addressed topics related to the wood production chain were excluded. Additionally, studies that were not available in full text or exhibited low methodological quality were also excluded.

Finally, the selected studies were carefully read, and their information was meticulously documented in a spreadsheet. The main findings were synthesized and thoroughly discussed in the literature review section of this work, allowing for the identification of both challenges and opportunities for the sustainable development of the wood production chain. This rigorous process played a pivotal role in determining the key themes and focal points that should guide the questionnaire implemented in the subsequent phase of the case study.

In the following section, we will outline the case study procedure adopted in this research.

3.1 Case study

The case study is a research methodology that seeks to enhance the understanding of a specific phenomenon, often characterized by its unique or particular nature (ANTWI; HAMZA, 2015). In this work, a case study was conducted in a timber company situated in the municipality of Porto Acre/AC. Data collection took place in

person during April 2023, utilizing a semi-structured questionnaire administered to the manager of the company being investigated.

The questionnaire was designed based on the insights gathered from the literature review, which allowed for the identification of the most relevant topics to be explored. It consisted of 12 questions that delved into areas such as forest management, extraction, transportation, storage, and product marketing. The objective was to gain a thorough understanding of the wood production chain within the studied company. These aspects were deemed essential for acquiring a comprehensive and detailed overview of the entire process, spanning from the raw material's origin to its market arrival. By addressing these questions, the intention was to analyze the company's practices, identify potential challenges and opportunities in the production chain, and assess compliance with environmental regulations and sustainability practices.

The semi-structured questionnaire is a data collection technique that provides flexibility in addressing topics. It combines pre-defined questions with open-ended responses, allowing the interviewee to provide detailed explanations (KALLIO et al., 2016). The in-person administration of the questionnaire facilitated greater interaction between the interviewer and the interviewee, fostering the clarification of doubts and the acquisition of more precise information.

The objective of the case study was to gain a comprehensive understanding of the wood production chain within the examined company, while identifying challenges and opportunities for the sustainable development of the sector.

3.2 Company presentation

The company examined in this research is situated in Porto Acre, a municipality in the state of Acre, and is engaged in every aspect of the wood production chain, ranging from forest management to the sale of the final product. Established in 1998, the company presently employs a committed workforce of 100 individuals. Its infrastructure encompasses a vast farm spanning over 10,000 hectares, where sustainable forest management practices are implemented. Furthermore, the company boasts a cutting-edge sawmill equipped with advanced technology, facilitating efficient wood processing.

For the marketing of finished products, the company has a network of three strategically located stores. This integrated structure enables the company to have control over the entire production process, from responsible forest management to the delivery of high-quality products to customers. Its production line focuses on manufacturing roof rafters, rafters, various types of boards, slats, and braces for formwork. It also produces battens, pillars, fence rails, and pool decks.

The company is renowned in the market for its strong dedication to sustainability and environmental protection, evident in its responsible forest management practices and the implementation of clean technologies throughout its production process. With an extensive product portfolio, it caters to both local and national markets, providing materials to other wood industry retailers, construction firms, contractors, and discerning end consumers who prioritize quality and reliability in their products.

4. Results and Discussion

The wood production chain in Brazil is a complex system, as highlighted in the literature review, involving the collaboration of various stakeholders to meet consumer demands. The country possesses extensive forested areas and a diverse range of species, playing a significant role in the global forestry sector. The forestry activities

encompass both the extraction of native forests and reforestation, both of which are pivotal in the production of timber and non-timber products. The Brazilian Forest Code holds a crucial position in regulating the exploitation of forest resources, aiming to strike a balance between economic growth and environmental preservation. The wood industry is characterized by its diversity, encompassing multiple sectors and offering a wide array of products, including energy and charcoal, pulp, sawn timber, as well as non-timber products like resins and rubber.

In the following section, the results of the research will be presented, which encompassed a semi-structured interview with the manager of a timber company located in the state of Acre. The collected data underwent meticulous analysis and were compared with the existing literature. This approach yielded valuable insights into the wood production chain, enhancing our understanding of the subject and offering a broader perspective on the industry's practices and challenges. The combination of interview findings and literature contributes to a more comprehensive and well-grounded comprehension of the topic.

4.1 Forest management: stages and precautions in wood extraction

During the questionnaire administration, it was discovered that the wood extraction process starts with a meticulous analysis of documentation, laws, maps, and field surveys. Using this information, projects are created to determine the species that can be harvested, considering factors like the number of trees per hectare. During the selection process, special attention is given to separating young trees, while preserving seedlings. Riparian areas, such as strips adjacent to streams and springs, are also duly recognized as Permanent Preservation Areas to guarantee ecosystem preservation.

Upon reaching this stage, the project undergoes evaluation by the regulatory authority (IBAMA), which has the authority to request any necessary modifications to ensure compliance with forestry management laws. The company overseeing the timber extraction process, which serves as the focal point of the study, meticulously strategizes each phase and proceeds to extract the wood to the sawmill, typically employing trucks, solely following the regulatory body's approval and prior to initiating the cutting process.

Following the approval of the project presented by the forestry engineer to IBAMA, actions are taken to commence the timber exploitation process. Firstly, a comprehensive camp infrastructure is established, which includes a fully-equipped office with satellite internet connectivity. It is noteworthy that Brazil is a member of the International Labor Organization (ILO), which, in collaboration with the Brazilian Forest Service (SFB), holds responsibility for managing federally-owned forest areas under concession. In 2009, the ILO and SFB jointly published a guidebook (ILO, 2009) with the objective of providing information that supports all stakeholders in safeguarding the rights of forest workers. Additionally, Brazil has specific legislations in place to protect the rights of both rural and urban workers, such as the Consolidation of Labor Laws (CLT).

The Regulatory Standards NR 24 (BRAZIL, 2023a) and NR 31 (BRAZIL, 2023b) establish essential regulations pertaining to the living quarters, dining facilities, and accommodations for workers. These standards are in place to ensure suitable housing conditions, including the provision of lockers, sanitary bathrooms, adequate electrical lighting, and a safe distance from generators to avoid disruptions during worker rest periods. Additionally, these NRs set forth work schedules designed to prevent exhaustion, mandate well-equipped kitchens and well-ventilated dining areas, and

require meals to be served in thermal containers. These regulations collectively guarantee a secure and healthy working environment for forestry workers.

Once the camp structure is properly established, the interviewee explains that the next step is to commence the process of identifying the selected trees. This identification is done using GPS technology and marking the trees with brightly colored TNT ribbons, which are crafted from polyester and polypropylene materials. To facilitate the felling of the chosen trees, the assistant to the chainsaw operator clears the tree stumps, preparing them for extraction. Additionally, a network of roads and trails is created throughout the forest to ease the transportation of the harvested timber to a designated yard. It is crucial to highlight that the location of this yard must be identified and approved by IBAMA to ensure compliance with environmental and forestry management regulations.

During the interview, the manager emphasized the utmost importance of preserving sensitive areas, particularly during the rainy season. Steep terrains and flooded zones serve as prime examples of such areas, as they are particularly susceptible to ecological damage. In the state of Acre, an additional challenge arises due to soil stability concerns during the "Amazonian winter" period. In the Amazon region, there is typically a dry season lasting 4 to 6 months and a rainy season lasting 6 to 8 months throughout the year (MIRANDA et al., 2022). This climate pattern restricts timber extraction to months with minimal or no precipitation. It was also mentioned with regret that the regulatory authority often issues the extraction permit only after the loss of several working days, leading to significant delays in the process.

The exploitation of native forests is a significant economic activity, but it must be conducted in a sustainable manner to ensure the preservation of fauna and flora (MELESE, 2016). It is of utmost importance to completely prohibit any exploitation activities within riparian protection areas (APPs) since these areas are sensitive and play a vital role in maintaining ecological balance. Apart from promoting environmental sustainability, preserving APPs can also yield economic and social benefits, including the conservation of natural resources and the promotion of ecotourism (BOLEY; GREEN, 2016).

In order to guarantee the preservation of riparian protection areas (APPs), several measures are implemented, including the exclusion of these areas from the forest management plan and the establishment of protection zones (LOPES et al., 2021). Additionally, conducting a thorough survey of the designated area is crucial to identify the species eligible for harvesting and to establish criteria for tree selection. Throughout the selection process, special attention should be given to safeguarding young trees and seedlings, thus ensuring the natural regeneration of the forest (KHASANOVA et al., 2021).

As mentioned by the interviewee, the company had previously obtained Forest Stewardship Council (FSC) certification as a result of its efforts, which was a requirement for exports. However, due to the high associated costs, the company is no longer certified. Nonetheless, the company continues to adhere to sustainable practices that are deeply ingrained in its culture. The FSC certification is a recognized emblem that signifies compliance with the highest market standards for forest producers. It is awarded to forest products, whether they are timber or non-timber, originating from responsibly managed forests that provide environmental, social, and economic benefits (MOOG et al., 2015).

Despite the challenges mentioned, the interviewee emphasizes the existence of environmental obstacles that serve the purpose of preserving the forest but inadvertently affect law-abiding entrepreneurs. However, these laws are necessary to

deter illegal extraction conducted by opportunistic individuals. It is crucial to highlight that even in a managed forest, despite its vastness, ongoing surveillance is required to prevent the infiltration of illegal loggers who may unlawfully harvest trees under the custody of responsible companies. Failure to prevent such incidents could lead to the suspension of the environmental license.

4.2 The logistics of timber extraction in native forests

When discussing the logistics of timber extraction, the manager emphasized that in the timber industry within native forests, the responsibility for constructing and maintaining access roads and logging trails often falls on the logging companies rather than the government. This necessitates a substantial private capital investment for the establishment of logging trails and the construction of bridges. Even in cases where the government maintains the logging trails, frequent repairs are required, such as bridges renovations, drainage improvements to prevent mudslides, and the use of high-quality materials in lower-lying areas to ensure the safe passage of heavily loaded trucks.

The productivity of the forest management project relies heavily on the utilization of mechanized patrols, which comprise various heavy machinery. The motor grader, also known as a patrol, is employed to clear logging trails, while crawler tractors are used for opening new trails and paths. Skidders, which are articulated forestry tractors, are responsible for dragging the logs to the designated yard, and the front-end loader is used to load trucks with the cleared logs. Moreover, the wheel loader is frequently employed to pull trucks out of muddy areas, ensuring efficient transportation. Figure 3 below provides an illustration of the forestry machines utilized in the wood extraction operation.

Figure 3: Forestry machines used in wood extraction

Patrol/Motor Grader – Model 670G

Crawler Tractor – Model 700J-I

Cable Skidder – Model 640L

Wheel Loader with Forks – Model 644K

Source: Adapted from Deere (2023).

In order to traverse small streams and creeks, temporary bridges are built using tree trunks. These bridges provide a passage for vehicles and equipment. In designated open areas called yards, skidders are employed to drag the logs, while a wheel loader assists in loading them onto trucks. Within these yards, the logs are meticulously sorted and stacked, preparing them for transportation.

The careful selection of yard locations is of utmost importance to ensure the preservation of the forest as a sustainable resource in the long run. Construction plans must be thoughtfully devised, taking into account the company's responsibility for biodiversity conservation and ecosystem protection. By prioritizing these considerations, we can foster a harmonious balance between industrial operations and environmental stewardship.

The yards should be strategically positioned in central areas, ensuring accessibility through roads that can accommodate truck traffic. This approach aims to minimize the necessity for additional deforestation. Furthermore, it is crucial to conduct thorough evaluations to identify potential sensitive areas, such as riparian zones, and take measures to prevent any adverse effects on the local wildlife and vegetation. By carefully considering these factors, we can promote sustainable practices that harmonize industrial activities with the preservation of the natural environment (NÓBREGA et al., 2020).

According to the interviewee's report, tree extraction in the Amazon region continues to rely on chainsaws as a common practice. The company diligently plans the cuts to ensure minimal impact on the trees designated for preservation. Once the trees are felled, the branches are carefully removed to facilitate log transportation. It is crucial to emphasize the importance of preventing log crushing and scarring, as these factors can significantly affect the quality of the wood. The company demonstrates a deep understanding of the significance of preserving the remaining trees and handles them with utmost care. The adoption of modern equipment for tree extraction has played a pivotal role in reducing the overall damage inflicted during the process.

Although skidding practices have evolved over time, the transportation of logs to the landing still involves the process of lifting and dragging them along the ground. In the past, this technique relied on teams of animals, including horses, mules, or oxen. Once the logs reach the loading site, the forestry workers meticulously select them, taking into account their species and diameter, in order to assemble the load and measure it for the subsequent issuance of the Forest Origin Document (DOF). This essential document is utilized to monitor and control the exploitation, transportation, and trade of forest products, such as wood and its derivatives. Its purpose is to combat illegal deforestation and promote sustainability within the forest production chain (BRANDES et al., 2020).

At the loading site, the logs undergo evaluation and selection in order to issue the Forest Origin Document (DOF). Measurements are taken to estimate the size of each log, while classification determines the wood's quality, considering factors such as branch marks and signs of decay. Skilled loggers employ techniques that optimize both the scale and quality of the wood during the cutting phase. Following the cutting process, the logs are loaded onto trucks using a wheel loader and transported to the company's sawmill.

The timber logs are transported from the extraction area to the sawmill using bi-train or road train trucks. Throughout the transportation process, the motor grader plays a crucial role by providing support on sections that are prone to muddy conditions, especially during periods of heavy rainfall. This ensures that the

transportation is carried out in a safe and efficient manner, minimizing the risk of accidents or delays.

Once the logs arrive at the sawmill, they are unloaded using another wheel loader, which carefully transports them to the area where the sawing process takes place. This machine also plays a crucial role in removing excess sawdust, which is then sent to various industries, including ceramics, where it is used in the production of bricks. In addition to transporting logs, trucks are also responsible for transporting firewood produced at the sawmill. This firewood serves as a valuable resource for industries such as feed factories, slaughterhouses, and bakeries, meeting their energy needs.

The manager emphasized that technological advancements have brought increased speed and efficiency to logging operations through the use of mechanization and reliable equipment designed for extreme conditions. However, despite these improvements, tree cutting activities are still regarded as highly dangerous, necessitating precautionary measures to prevent injuries. Skidders, the vehicles used for skidding logs, are equipped with protective cages and seat belts to ensure the operator's safety in the event of equipment overturning or falling tree branches. Chainsaws are equipped with safety features that enable quick shutdown in emergencies. Additionally, workers wear personal protective equipment, including helmets, ear protectors, face shields, steel-toed boots, and leg guards, to minimize risks. The clothing worn is made of durable materials and features vibrant colors. It also includes long sleeves to protect against insects. Recognizing the intense heat experienced in the forest and the challenges of mobility, the clothing is crafted from lightweight and flexible materials to provide optimal comfort during forest activities.

4.3 Production process in the sawmill

The sawmill of the company under study is equipped with three band saws powered by electric motors, demanding a substantial amount of electrical energy. To address this, a solar park project was implemented on the premises last year, comprising 630 solar panels. As of now, this endeavor has become the largest privately-owned energy generator in the state of Acre, leading to a noteworthy reduction in electricity expenses for the sawmill.

At the site, there is a skilled worker known as a peeler, assigned with the task of removing the bark from the log to eliminate sand, facilitate the cutting process with the band saw, and prevent damage to the equipment. Following this step, in what is referred to as the primary breakdown, the peeled log is positioned on a sturdy steel carriage that transports it through a band saw—a saw bench equipped with flexible steel teeth mounted on wheels above and below the log to be cut. As the log passes through, the saw removes wooden planks, creating a rectangular block commonly referred to as a flitch. In the subsequent secondary processing stage, the flitch is further sliced into boards that are carefully trimmed and adjusted to achieve the desired lengths and widths. This meticulous process not only enhances the quality of the wood but also adds value by eliminating any imperfections.

Subsequently, the wood is sorted by species and classification and undergoes either air-drying or kiln-drying, depending on its intended purpose. It is crucial for the wood to undergo a slow and uniform drying process to avoid cracks and deformations. The finishing process varies based on the specific species and the desired final product. Some woods are sold without any finishing treatment, while others are planed to achieve a smooth surface. Furthermore, the boards may be treated with chemicals to protect against decay.

Advancements in wood cutting technologies have been made to enhance the efficiency of extracting usable wood from a log, commonly referred to as the sawn wood recovery factor. A notable example is the utilization of high-quality steels, enabling the use of thinner saw blades. This reduction in cutting kerf minimizes the amount of wood lost during the cutting process. Moreover, modern sawmills employ laser scanners and computational technology to precisely determine the optimal cuts. By maximizing both the value and volume of wood boards obtainable from a log, these cutting-edge techniques significantly improve overall efficiency and productivity (STÄNGLE et al., 2015).

The origin and path of the wood are meticulously documented using a unique identification number assigned to the tree within the project, the remaining stump after cutting, and the transported log, along with the Document of Forest Origin (DOF). After undergoing the transformation process into sawn wood, the log is assigned a transformation coefficient, leading to the generation of a new DOF. This enables the legal transportation of the wood to a designated warehouse or timber store, where it is carefully allocated and tracked through the IBAMA website. This comprehensive inventory management generates another DOF for the end consumer or company. The entire process, known as the Chain of Custody, plays a critical role in tracing the wood's origin and is mandatory for exportation or for clients adhering to comprehensive quality programs, in compliance with the NBR 14790 standard.

5. Conclusion

The comprehensive literature review undertaken thoroughly examined the wood extraction process, the various sectors involved in this field, and the measures implemented to ensure sustainable exploitation in adherence to environmental legislation. Within this context, the company under analysis, operating across the entire wood production chain, exemplifies the possibility of harmonizing economic resource exploitation with environmental preservation. Through responsible forest management and the adoption of clean technologies, this company distinguishes itself in the market, owing to its outstanding dedication to sustainability and the environment.

When developing a forest management project, the company relies on meticulous analysis that considers various aspects, including careful tree selection, preservation of permanent protected areas, natural forest regeneration, and limitations on tree felling. These measures are vital for ensuring ecosystem preservation and the sustainability of economic activities. Delimiting protection zones, excluding permanent preservation areas, and conducting detailed surveys of the designated exploitation areas are crucial steps to ensure the preservation of fauna, flora, and natural forest regeneration. In addition to the environmental benefits, the preservation of permanent protected areas also brings economic and social advantages, such as the maintenance of natural resources and the promotion of ecotourism.

While forest management activities present challenges, such as restrictions on tree felling and the protection of sensitive areas, it is vital for timber extraction companies to embrace sustainable practices. By doing so, we can guarantee the preservation of ecosystems, natural forest regeneration, and the sustainability of economic activities. Preserving native forests is a collective responsibility and must be prioritized for environmental and social sustainability. The company being analyzed serves as an exemplar of how economic development and environmental preservation can be harmonized through the implementation of responsible and sustainable timber extraction measures.

In conclusion, the process of timber extraction in native forests requires careful planning and responsible execution to ensure the preservation of ecosystems and the sustainability of the activity. Critical measures, such as excluding permanent preservation areas and establishing protection zones, are essential for guaranteeing biodiversity conservation. Additionally, the meticulous selection of trees and the use of modern equipment play a significant role in minimizing damage and promoting natural forest regeneration. It is crucial to adopt certified practices, such as obtaining FSC certification, and to adhere to labor standards, ensuring environmental responsibility and the well-being of workers. Transportation logistics also have a crucial role, necessitating investments in appropriate infrastructure, such as roads and bridges, to enable access to extraction areas. With a continuous commitment to responsible forest management, it is possible to harmonize economic activity with nature conservation, securing a sustainable future for native forests.

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