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Environmental Life Cycle Assessment of industrial pine roundwood production in Brazilian forests

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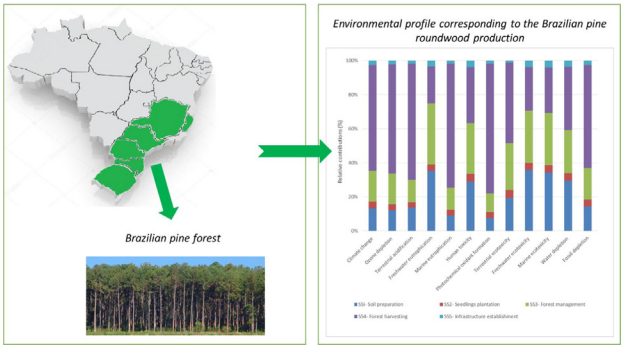
HIGHLIGHTS

- A detailed environmental analysis of pine roundwood was performed.
- Brazilian current forest practices were considered.
- Forest harvesting related operations were identified as hotspot.
- Diesel requirement and fertilizers application played a key role.
- Optimization of forest practices is required to improve the environmental profile.

GRAPHICAL ABSTRACT



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ABSTRACT

Pine (*Pinus oocarpa*) wood has great economic importance in Brazil. Pine stands represent the second largest reforested area in the country due to their industrial interest. Combining the relevance of industrial pine stands in the country and corresponding environmental concerns, this current study aims to identify and quantify the environmental impacts derived from industrial pine roundwood production in Brazil. The environmental study was developed considering the Life Cycle Assessment (LCA) methodology according to ISO14040 framework. The study convers the life cycle of pine roundwood production from cradle-to-forest gate perspective and considers the current practices in the country. The production system was divided in five main stages: Soil preparation, seedlings plantation, forest management, forest harvesting and infrastructure establishment. The environmental profile was estimated considering characterization factors from the ReCiPe method, in terms of twelve impact categories. According to the results, forest harvesting stage was identified as the environmental hotspot being the main responsible of contributions to nine impact categories under assessment with contributing ratios ranging from 21% (e.g., freshwater eutrophication) to 76% (e.g., photochemical oxidants formation). The high amount of fossil fuel required by heavy machinery used in the activities involved in this stage is behind this result. Soil preparation stage reported also an outstanding contribution in categories such as freshwater eutrophication (37%) and toxicity related categories (≈35%). The rationale behind these contributions is associated with the use of chemical fertilizers, mostly superphosphate. The identification of the environmental hotspots in forest biomass production can assist the Brazilian forest practitioners to improve the environmental profile by means of the optimization of forest practices.

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1. Introduction

In Brazil, the forestry activities have great relevance not only due to the extensive forest cover that exists in the country but also because of their employment capacity and incomes generation within the sector. The last study performed by the Brazilian forest service (IBÁ, 2016) showed that approximately 60% of the Brazilian national territory (493.5 million ha) is covered by forest. Moreover, it was estimated that the forestry sector derived on 3.7 million direct and indirect jobs and the income generated by the sector was around 3 billion US dollars (IBÁ, 2016).

Regarding to the reforestation area in Brazil, it corresponds to 7.84 million ha, and of this total, around 20% corresponds to pine-based reforested stands. Pine is the second most important forest specie planted in the country, after *Eucalyptus*, being mostly destined to the production of cellulosic pulp (IBÁ, 2016). Throughout many years, different pine species originating from different countries all over the world were introduced in Brazil to produce the biomass used as raw material in wood industry for multiple applications (Shimizu, 2006). European pine such as *Pinus canariensis* was introduced in Brazil for silvicultural purposes in 1936 (Shimizu, 2006). American pine species such as *Pinus palustris*, *Pinus echinata*, *Pinus elliottii* and *Pinus taeda* were introduced by Forestry Service of São Paulo State (Shimizu, 2006) in 1948. *Pinus elliottii* and *Pinus taeda* stand out between others due to their fast growth in Southern and Southeastern Brazilian regions (Shimizu, 2006). The increase in the demand of wood derived into new pine-based plantations. As a result, new species started to be planted and commercialized such as *Pinus caribaea* and *Pinus oocarpa*, being the cultivation of the latter highlighted in the country due to its high potential growth in low fertility areas.

The forest area dedicated to pine stands in Brazil was around 1.5 million ha in 2012 (ABRAF, 2013). Around 90% of this total area is concentrated in Southern regions mostly due to the climate and soil conditions. The State of Paraná leads the ranking of total planted area (39.7%), followed by Santa Catarina (34.5%), Rio Grande do Sul (10.5%) and São Paulo (9.3%) as displayed in Fig. 1 (ABRAF, 2013). Regarding the average production of pine roundwood in the country mostly dedicated to industrial use, it was around 47.6 million m^3 in 2012 (ABRAF, 2013).

After harvesting, the timber can be allocated to the laminating industry for plywood manufacturing (Iwakiri et al., 2005), to construction purposes (Zenid et al., 2009; Icimoto, 2012) or it can also be destined to the production of woody products such as pulp and paper (Morais et al., 2005), medium density fibreboards (Silva et al., 2014), sawn wood (Murara Junior et al., 2005) or furniture (Mattos et al., 2008). Moreover, woody residues from forest plantations and wood processing can be used as biomass for heat and energy generation (Cargnin, 2005).

In recent years, forest activities are receiving special attention concerning the quantification of their environmental profiles to be more competitive at global scale (González-García et al., 2014a). Life Cycle Assessment (LCA) is a standardized methodology that allows assessing environmental impacts associated to materials, products and services throughout their production systems, as well as it can support on decision-making strategies towards sustainability (Baumann and Tillman, 2004).

Numerous environmental studies are available in literature with the aim of identifying the environmental profiles of dedicated industrial forest systems by means of LCA methodology. Examples can be found in Finland and Sweden with regard to the production of Norway spruce and Scots pine (Berg and Karjalainen, 2003), Maritime pine in

Fig. 1. Area and distribution of pine forest plantations throughout Brazil (ABRAF, 2013). Acronyms: AP - Amapá; TO - Tocantins; BA - Bahia; MG - Minas Gerais; GO - Goiás; MS - Mato Grasso do Sul; ES - Espírito Santo; SP - São Paulo; PR - Paraná; SC - Santa Catarina; RS - Rio Grande do Sul.